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Intelligent Chilled Mirror Humidity Sensor

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Intelligent Chilled Mirror Humidity Sensor

Abstract

A new, intelligent, chilled mirror humidity instrument has been designed for use on buoys and ships. The design goal is to make high quality dew point temperature measurements for a period of up to one year from an unattended platform, while consuming as little power as possible. Nominal system accuracy is 0.3°C , and a measure of data quality is provided to indicate possible drift in calibration. Energy consumption is typically 800 Joules per measurement; standby power consumption is 0.05 watts. Control of the instrument is managed by an on-board central processing unit which is programmable in BASIC, and communication to an external data logger is provided through an RS232 compatible interface. This report describes the preliminary sensor tests that led to this new design and provides the complete technical description required for fabrication.

I. Introduction

A new humidity measuring instrument has been developed as part of the Upper Ocean Observing System / Surface Meteorology program sponsored by the Office of Naval Research. The long-term goal of that program is the development of a more capable and more cost-effective buoy system for upper ocean and air/sea interaction experiments. A key requirement is the evaluation of latent heat flux, which is dependent upon having accurate humidity measurements from within the marine planetary boundary layer. Most humidity sensors now in use are subject to unpredictable calibration drifts due to contamination. The goal of the development program for 1986-1987 was therefore narrowed to focus on the problem of making accurate, reliable humidity measurements from ships and unattended buoys.

In this report we describe a series of tests of commercially-available humidity instruments, and the motivation that led to the design of a new instrument called the D10IQ. We provide a complete technical description of the D10IQ, including all wiring and printed circuit board layouts required for fabrication.

II. System Requirements

The general requirements and criteria for a humidity instrument suitable for unattended, seagoing platforms were thought to be the following:

1. The instrument is to be mounted on a buoy or ship. It must run unattended and must survive in the near surface environment. (Some protection from direct spray was presumed to be available on the platform and is not to be provided with each instrument.)
2. The target life length is one year of unattended operation, with measurements made 8 times each day (roughly 3000 measurements).
3. Accuracy of a dew point measurement is to be within 0.5°C. Some means for warning of possible spurious data should be provided.
4. The instrument will be capable of being powered down between measurements to minimize power consumption.
5. The instrument should have a cost of less than about \$4,000 when produced in quantities of 50 per year.
6. The prototype instrument designed in 1986-1987 and described here will be flexible enough to permit reasonable modification after each test period, and to be adaptable to different platforms and different sea-going environments.

III. 1986 Tests

After a literature review (e.g., *Moisture and Humidity*, 1985), testing was begun on the W.H.O.I. dock to evaluate the most promising, commercially available humidity sensors. The humidity sensors acquired for test were the Rotronics Model MP 100 solid state sensor (Muller, 1985), the General Eastern Model 850 solid state sensor (Weisman, 1988) and the General Eastern Dew-10 chilled mirror dew point sensor (described in the next section).

A data collector was designed and built using a Tattletale 2 (trademark by Onset Computer Corp.) microcomputer. Figure 1 shows the equipment set up on

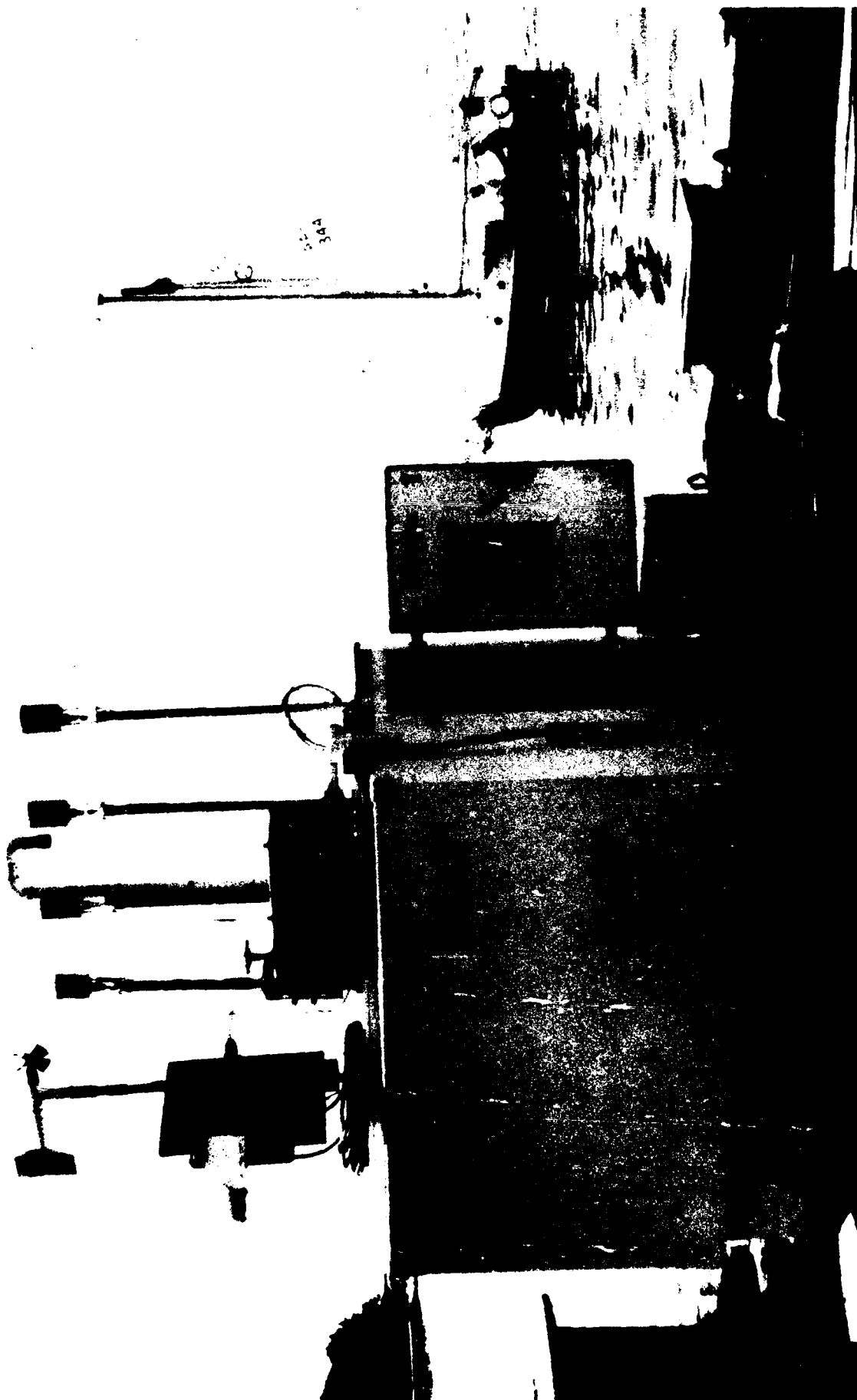


Figure 1. Photograph of the van set-up on the W.H.O.I. dock for the 1986 sensor tests (see also the schematic in Fig. 2). The Young anemometer is at upper left, and just below is the EG&G Dew Pointer. The four upright shrouded housings contain solid state sensors and thermistors.

a van on the W.H.O.I. dock, and Figure 2 is a schematic of the test configuration. The van provided a dry place to store the power supplies and the portable computer used to take the data from the Tattletale data collector. A sealed weather-tight box was fastened on top of the van to house the data collector, aspirator with Gore-Tex filters, barometric pressure sensor and other electronics. The sensors tied into the data collector included an R. M. Young wind speed and direction sensor, an Atmospheric Instrumentation Research Corp. barometric pressure sensor, and an EG&G Dew Pointer Humidity instrument that was intended to be used as a reference. Our unit proved unreliable and was eventually discarded from the tests. As a replacement, we chose a manually operated sling psychrometer (Assman Corp.) which, though tedious to operate, was found to be extremely reliable and held calibration very well. The humidity sensors tested were three Rotronics solid state relative humidity sensors, three General Eastern Instruments Corp. model 850 solid state relative humidity sensors, a General Eastern Instruments Corp. standard Dew-10 dew pointer humidity sensor, and one Dew-10 based breadboard Intelligent Dew-10 sensor, the first prototype of the system we developed fully in 1987 and called the D10IQ.

The calibration of both the Rotronics and General Eastern solid state sensors drifted with time and several sensors failed completely after only a few weeks of testing (details of the 1986 test results are listed Appendix A). Based upon this experience, and upon the tendency for this erratic behavior reported by others (Muller, 1985; Clarke and Painting, 1983), we concluded that these solid state sensors did not have the reliability required for long-term unattended use at sea. This is regrettable, as solid state sensors are comparatively low in cost and power consumption and small in size.

The chilled mirror Dew-10 sensors provided acceptable data for a considerably longer period, although they too eventually became fouled by a hydrocarbon-based residue on the mirrors. However, given this generally better performance, and upon the advice of General Eastern Corp. engineers who have had extensive experience with many types of humidity sensors, our focus turned toward using chilled mirror sensors as the basis of a new humidity instrument.

- Humidity Test Set Up**
- 1 Van (on dock)
 - 2 Portable (PC) Computer
 - 3 Power Supplies
 - 4 AC Power - 120V
 - 5 UART to Tattletale II
 - 6 Tattletale II, A/D, MUX, Signal Conditioning
 - 7 Sealed Box for Electronics
 - 8 Wind Speed and Direction
 - 9 EG&G Dew Pointer Humidity Reference
 - 10 (3) Rotronics Humidity Sensors
 - 11 (3) General Eastern 850 Humidity Sensors
 - 12 Air Intake for Aspirated Chamber
 - 13 Fan Speed Control (manual)
 - 14 Intelligent "DEW 10" Sensor (with auto pacer & nitrogen)
 - 15 Aspirated Chamber with Goretex Filters
 - 16 (2) Standard "DEW 10" Sensors (1 with manual clean & 1 with pacer clean)
 - 17 (2) Fans
 - 18 Air Outlet
 - 19 Barometric Pressure Sensor

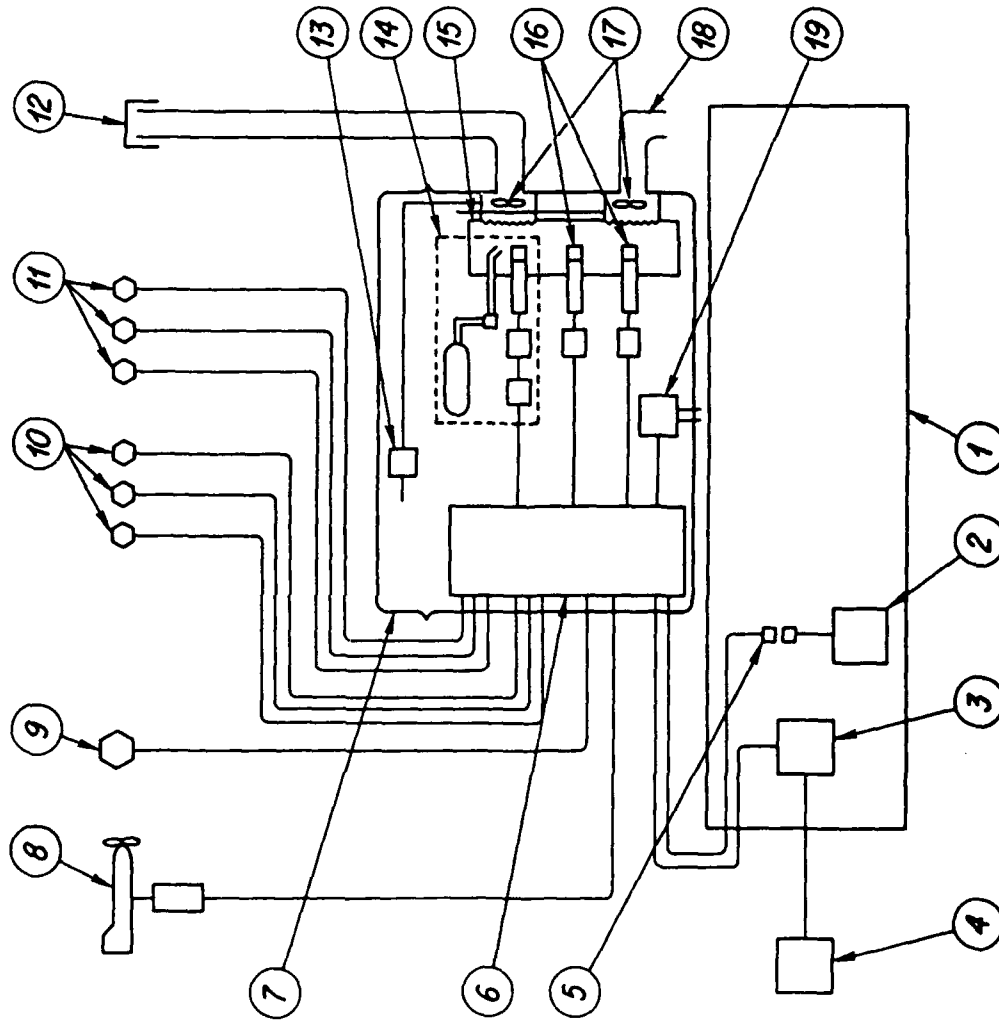


Figure 2. Schematic of the dock tests.

IV. Chilled Mirror Dew Point Sensor

A chilled mirror sensor measures dew point temperature, which is a primary measurement of humidity. (Solid state sensors generally measure the change in capacitance of a ceramic caused by changes in humidity.) Chilled mirror sensors have an excellent accuracy over a dynamic range that is more than sufficient for marine meteorological applications, Figure 3.

They operate in a straightforward way. A miniature thermoelectric heat pump cools a metallic mirror, causing a thin dew layer to condense on the surface when the temperature reaches the dew point of the surrounding air, Figure 4. Dew formation is optically detected, and a feedback loop keeps the mirror within a few tenths degree C of the dew point by continuously controlling its temperature. A platinum temperature probe is embedded just beneath the surface of the mirror, allowing the dew point temperature to be measured to within 0.2°C.

Calibration is achieved by an LED bridge, one side of which reflects light from the surface of the mirror while the other side provides a direct path reference (Figure 4). When the sensor is assembled, the reference side is balanced with a mechanical adjustment. During normal operation the mirror gets progressively dirtier. The balance must be adjusted electronically to lengthen the useful time that measurements can be made between cleanings. Once the mirror becomes excessively dirty, further electronic balancing is ineffective, and some form of cleaning is required.

General Eastern has developed a patented cleaning process called a "pacer cycle", Figure 5. By cooling the mirror well below the dew point, moisture eventually coalesces which tends to bring the surface contamination into solution. When the mirror is then heated, the moisture "pools" and evaporates leaving the contamination in small concentrations while leaving typically 85% of the mirror in a clean usable state. Thus the pacer cycle provides a means to greatly extend the useful life of an unattended, chilled mirror instrument, and, as we describe further below, has been implemented under software control in the new instrument.

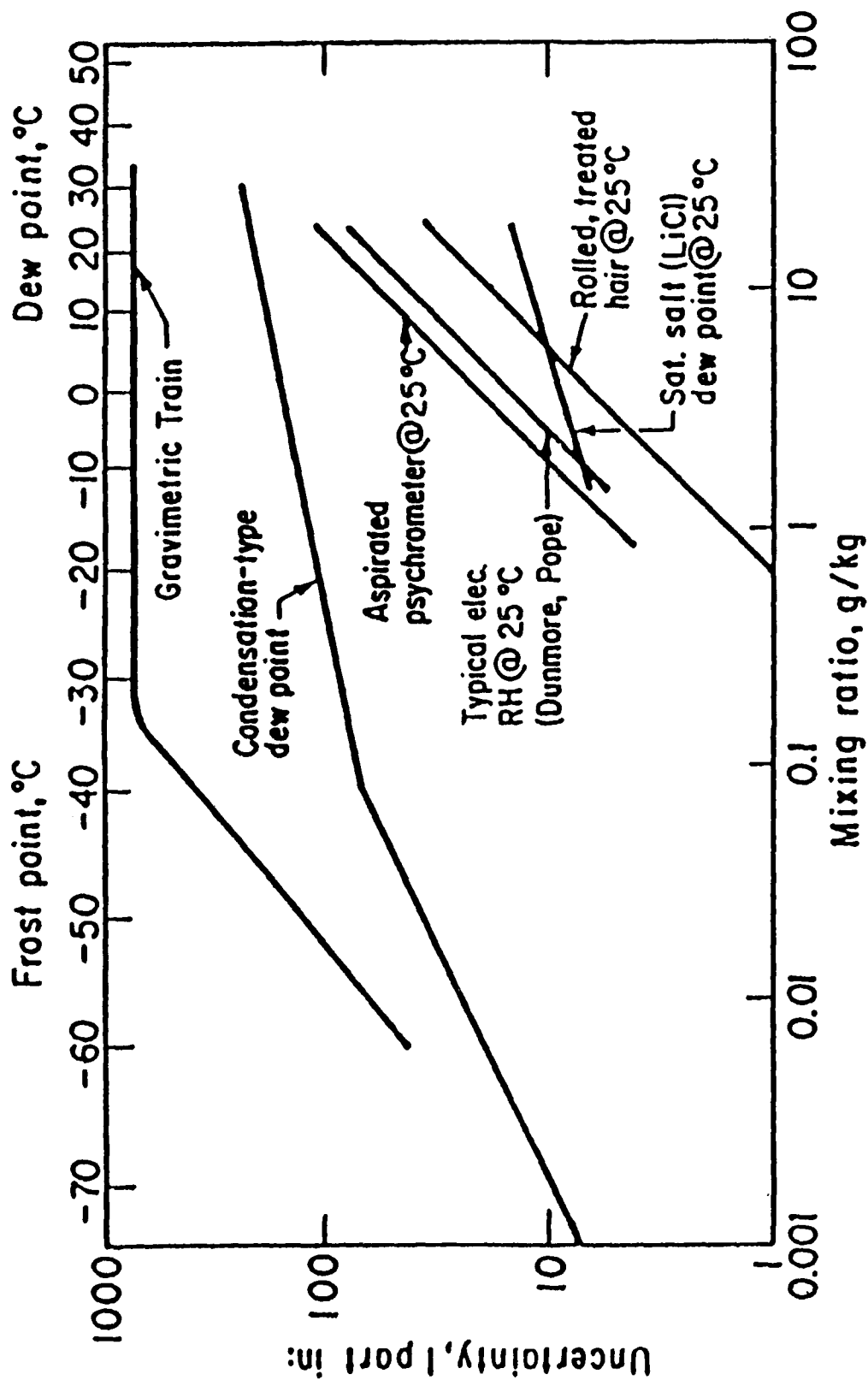
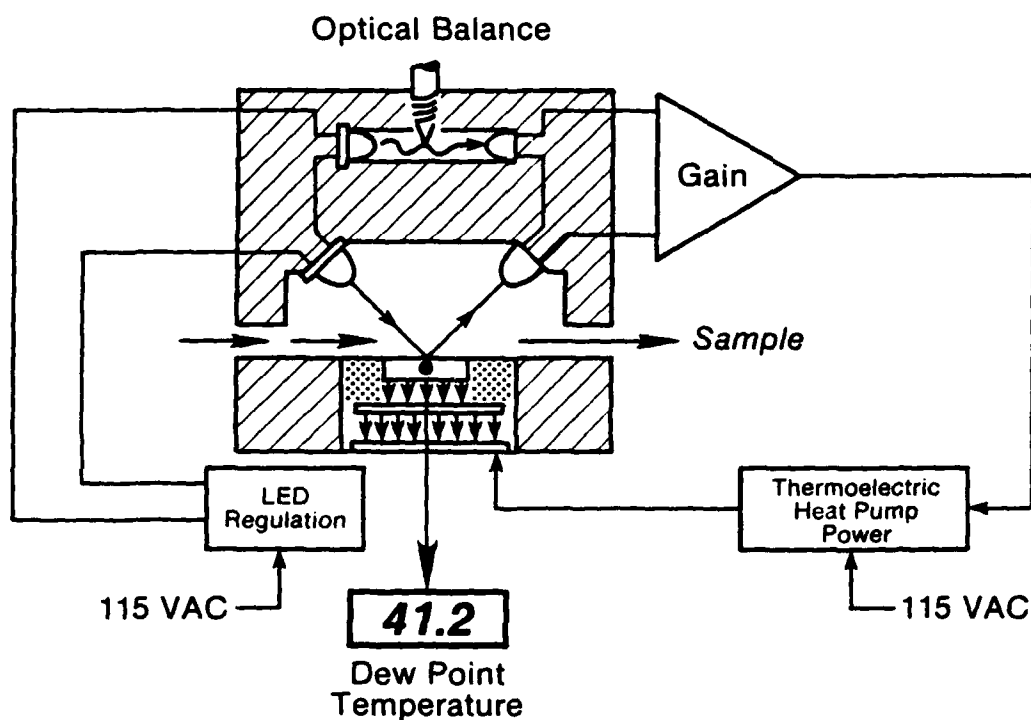


Figure 3. Measurement uncertainty as a function of dew point for a variety of widely used humidity sensors. Note that condensation-type dew point sensors such as chilled mirrors provide excellent accuracy over a very wide dew point range. From Wiederhold (1975).



Dew Point is detected in a condensation hygrometer by cooling a surface until water begins to condense. Condensation is detected optically or electronically, and the signal is fed into a control circuit which maintains the surface temperature at the precise Dew Point.

Figure 4. Schematic of the Dew-10 chilled mirror sensor. From Wiederhold (1975).

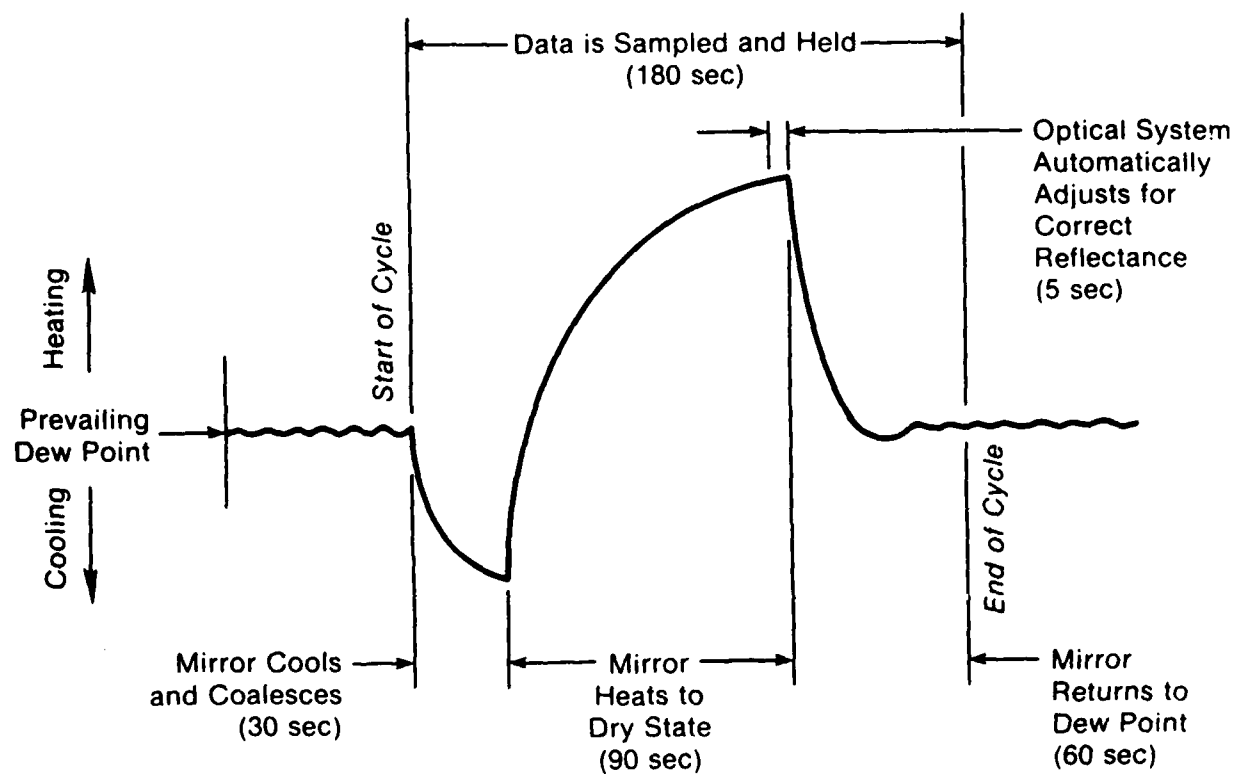


Figure 5. Schematic of the pacer cycle used to clean chilled mirror sensors. This is a patented process by General Eastern Instruments Corp. From Wiederhold (1975).

In addition to the dew point temperature, a quantity called *mirror voltage* is also measured by the Dew-10. This is a voltage proportional to the light reflecting from the mirror to the photo receiver. Mirror voltage is measured after a pacer cycle is completed so that the mirror is as clean as possible, and before the bridge is balanced so that it is a true measure of the mirror condition. When a mirror is clean, the mirror voltage is about 3.2 to 3.3 volts. When the mirror is too dirty for the sensor to operate properly, the mirror voltage is about 2.2 volts or less. By sending this mirror voltage value to the data collector along with the dew point temperature, a useful indicator of data quality can be obtained as a normal part of the data stream. Thus the Dew-10 can provide a useful measure of the most likely source of calibration drift, an important feature for long-term, unattended use.

V. Design and Testing of the D10IQ

The generally favorable 1986 test results and the inherent qualities of the chilled mirror sensors encouraged us to begin the design of a computer-controlled chilled mirror instrument built around the Dew-10 sensor. It was given the name D10IQ for Dew-10 intelligent humidity sensor (humidity is often represented by "q"). The design problem was to provide the best possible protection of the sensor while retaining the necessary measurement accuracy, and to provide for as much self-cleaning as was possible within reasonable cost and power constraints. Computer control of the D10IQ was necessary to provide communication with data loggers and could also be used to drive the pacer cycle or other cleaning and protection processes. The now-somewhat-refined goals for the D10IQ were that it provide:

1. a primary sensing device of dew point temperature in the range from -10°C to $+35^{\circ}\text{C}$, and accuracy of $\pm 0.5^{\circ}\text{C}$;
2. intelligent, software controlled operation, and data communications through a standard RS232 interface;
3. data quality indication via mirror voltage;
4. self cleaning by the pacer cycle, and sensor protection;

5. minimum power consumption; and
6. reasonable cost, less than \$4,000 in lots of 50.

The first breadboard level D10IQ electronics package was fabricated to our design by General Eastern Instruments Corp. in early 1987 to permit testing the concept of a microprocessor-controlled dew point sensor that could turn power on and off and implement the pacer cycle in software. A standard Dew-10 sensor, the breadboard Intelligent Dew-10 sensor, and an aspirated sling psychrometer were operated on the W.H.O.I. dock during a second series of tests beginning in the fall of 1987.

From these test results, Figure 6, it can be seen that from day 229 through day 260, the dew point temperature from the D10IQ, the dew point temperature from the standard Dew-10 sensor, and the equivalent dew point temperature taken from the manually-operated sling psychrometer match with great accuracy. Note that during this time, the mirror voltage was slowly falling from 3.1 volts to near the 2.2 volt limit as the mirrors become progressively dirtier. Unfortunately the data from day 260 to 268 was lost due to an electrical storm which knocked out power to the van. When the data resumed, the mirror voltage was below the 2.2 volt limit and neither Dew-10 sensor was providing good data. This gives us some confidence that when the mirror voltage is in its proper range, the measured dew-point temperature should be within tolerance, and that mirror voltage can be used in the data reduction process to indicate when the data should no longer be used.

With continuous aspiration the sensors fouled in about 31 days. (Both the standard Dew-10 and the D10IQ gave the same results.) This test result suggests that if the sensor head could be protected from the environment between measurements, then reliable dew point temperature data could be obtained for long periods in an unattended location. (Since the average time for making a measurement is about 3 minutes, making a measurement once every 60 minutes should provide a roughly 20:1 increase in the sensor life.)

DEW 10 TESTS

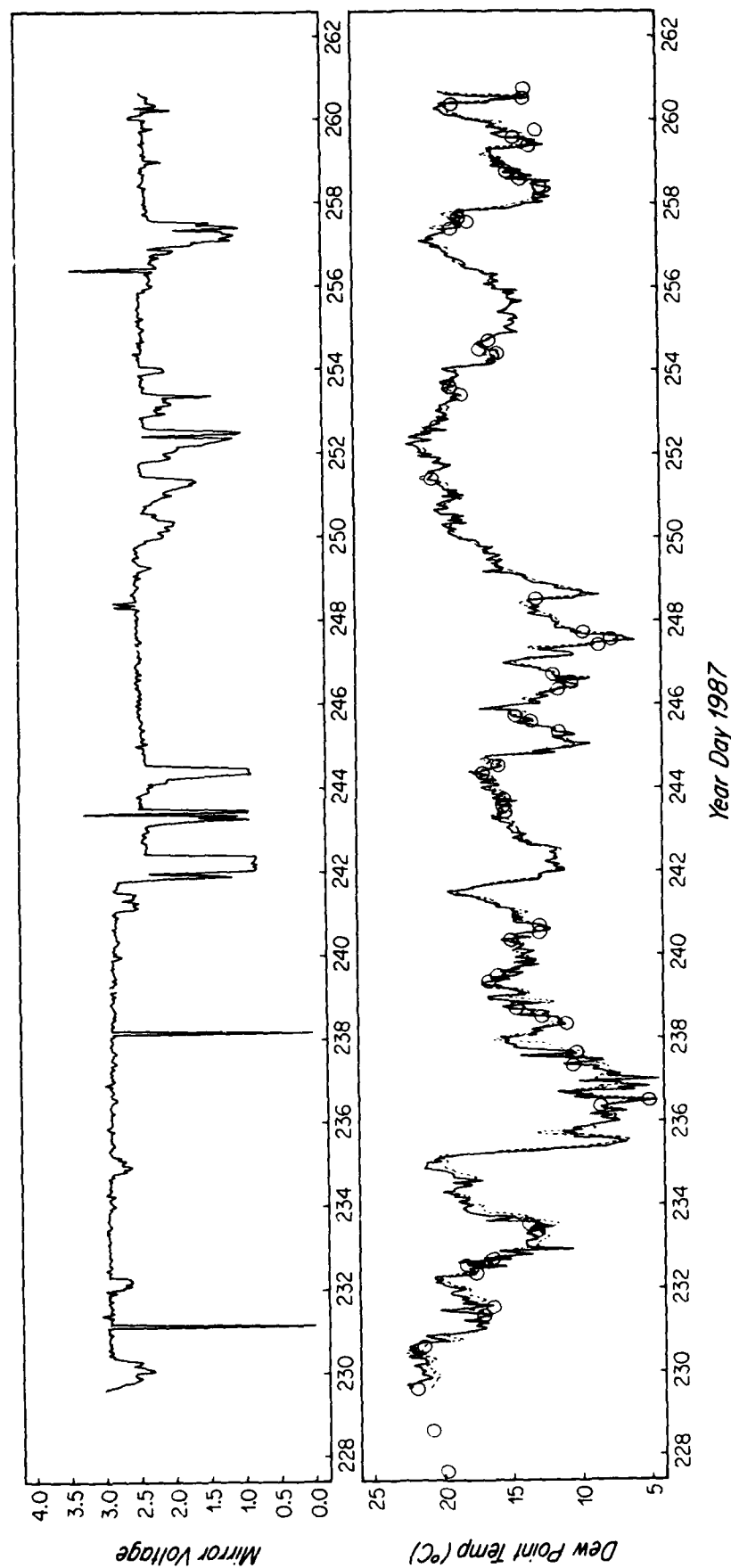


Figure 6a. Time series of dew point temperature as measured during the 1987 dock tests by a standard Dew-10 sensor (solid line), by the first breadboard D10IQ (dashed line), and individual data points measured by a manually operated sling psychrometer which is the reference. Note that both chilled mirror instruments provided very good dew point temperatures until about day 260 when a power failure caused a hard shutdown and data loss. When data logging resumed, both chilled mirrors had become fouled by hydrocarbon-based residue. See Figure 6b.

DEW 10 TESTS

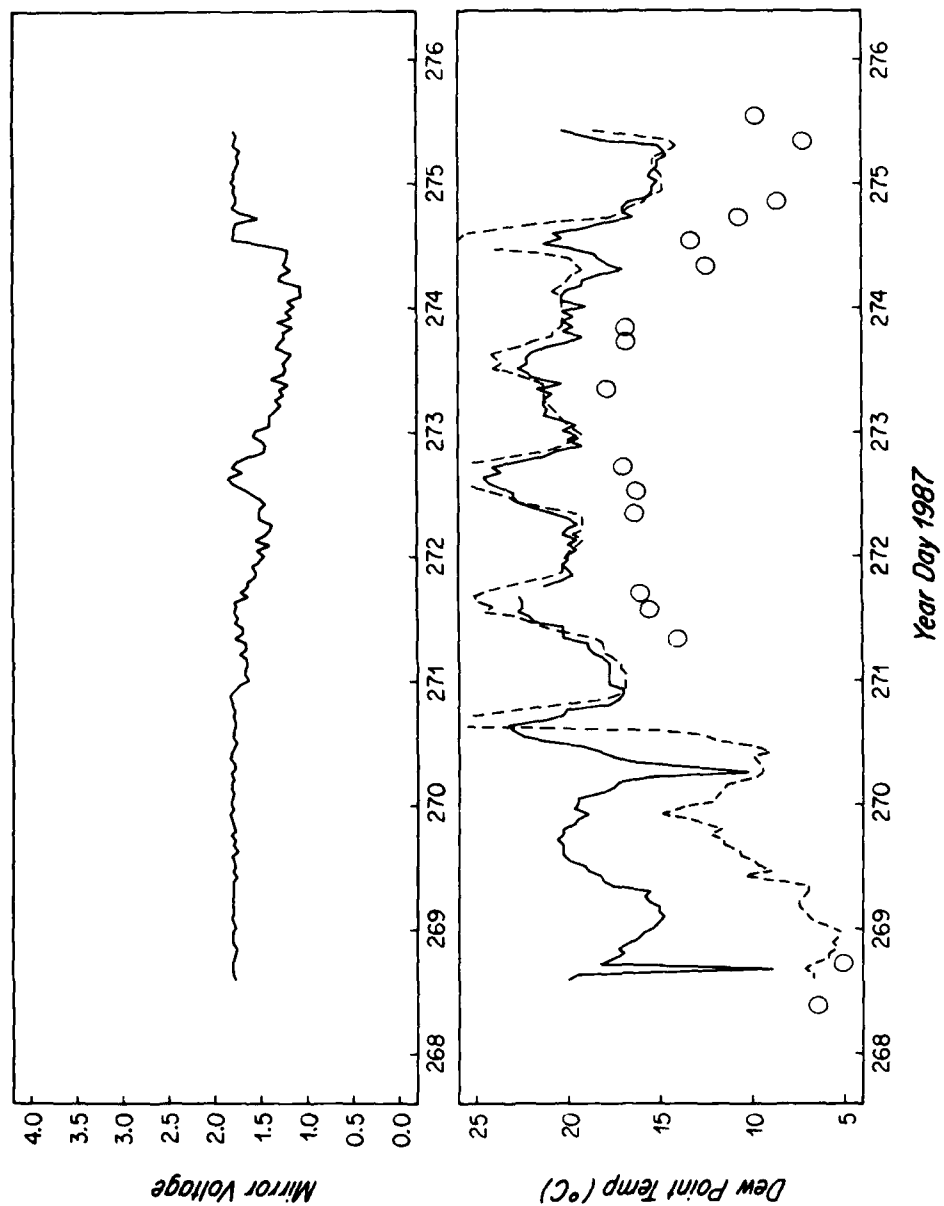


Figure 6b. Test data for days 268 to 276.

To provide for better protection of the sensor, two additional features were implemented in the D10IQ following the 1987 tests. First, the sensor head cavity was enclosed in a rotating sleeve that could be opened and closed under software control; it is opened just before a measurement cycle and closed at the end of a measurement cycle, which should eliminate any contamination of the mirror during non-duty periods. Secondly, a nozzle and valve arrangement was designed to provide a short squirt of dry nitrogen onto the mirror. At present, this squirt comes after the sleeve has been closed so that the mirror is bathed in dry nitrogen during non-duty periods. A second possible use of the nitrogen jet would be as a supplemental cleaning step following the pacer cycle. If the contaminants were left in the form of a dry powder, then a nitrogen jet could be useful in removing the residue from the mirror. Whether this is useful in practice remains to be determined from field testing.

The sequence of operations in the D10IQ is as follows:

1. Wait for (*DTR) Data Request
2. At *DTR, Send Serial Data from Last Measurement
Ambient Temp. Dew Point Temp. Contamination Level
 TT.T TT.T V.VV
3. Rotating Seal Sleeve is Opened
4. Aspirator Fan is Turned On
5. Turn on Dew-10 Power
6. Measure Ambient Temperature
7. Pacer Cycle and Rebalance
8. Measure Contamination Voltage
9. Cool Mirror to Obtain Dew Layer, Let Settle
10. Measure Dew Point Temperature
11. Turn Off Aspirator
12. Close Seal
13. Use N₂ to Clean/Purge Sensor Chamber
14. Turn Off Dew-10 Power
15. (Return to 1.)

The final packaging and fabrication details were completed in summer 1988 to result in a highly modular, aspirator/electronics and housing/sensor/seal unit: Figures 7, 8, 9 and Table 1.

Table 1. Specifications of the D10IQ

Physical size	30" long × 4.5" diameter (without spray protection)
Weight	12.75 pounds
Power	12 volts DC, peak 600 milliamps, standby 3.5 milliamps, average 23 milliamps per hour with one pacer and sample per hour
Sample Time	3.5 minutes minimum
Data Request	Data request line goes from normal +5 volts to 0 volts DC
Data Output	Data out is serial ASCII with 5 volt logic. RS232 can be implemented.
Filters	Gore-Tex, 5 microns with 47 square inches area
Aspiration Rate	3 to 5 cubic feet per hour
N ₂ Supply	Maximum 100 psi of Nitrogen
CPU	6301 CMOS
Memory Life	The Tattletale IV has a lithium battery that provides up to 6 months of program and data protection with no outside power source.

Mechanical drawings are included in Appendix B for the parts that can be fabricated in either a laboratory shop or subcontracted to a machine shop. Printed circuit layouts are included for the small printed circuit electronics associated with the seal closure. The main parts including the dew point sensor and custom sensor drive electronics are available from the specified manufacturers. Assembly and wiring are then required by the laboratory making the units. The microprocessor

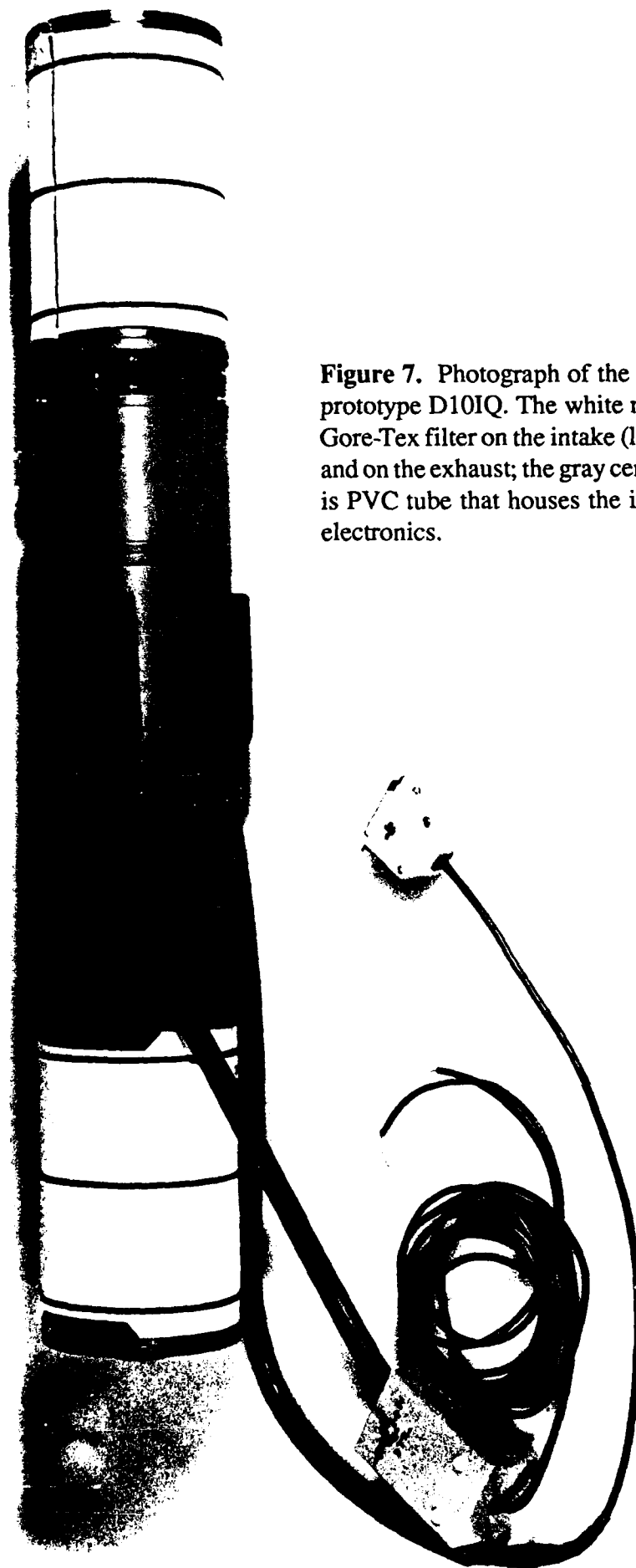


Figure 7. Photograph of the complete, prototype D10IQ. The white material is Gore-Tex filter on the intake (lower end) and on the exhaust; the gray central piece is PVC tube that houses the instrument electronics.

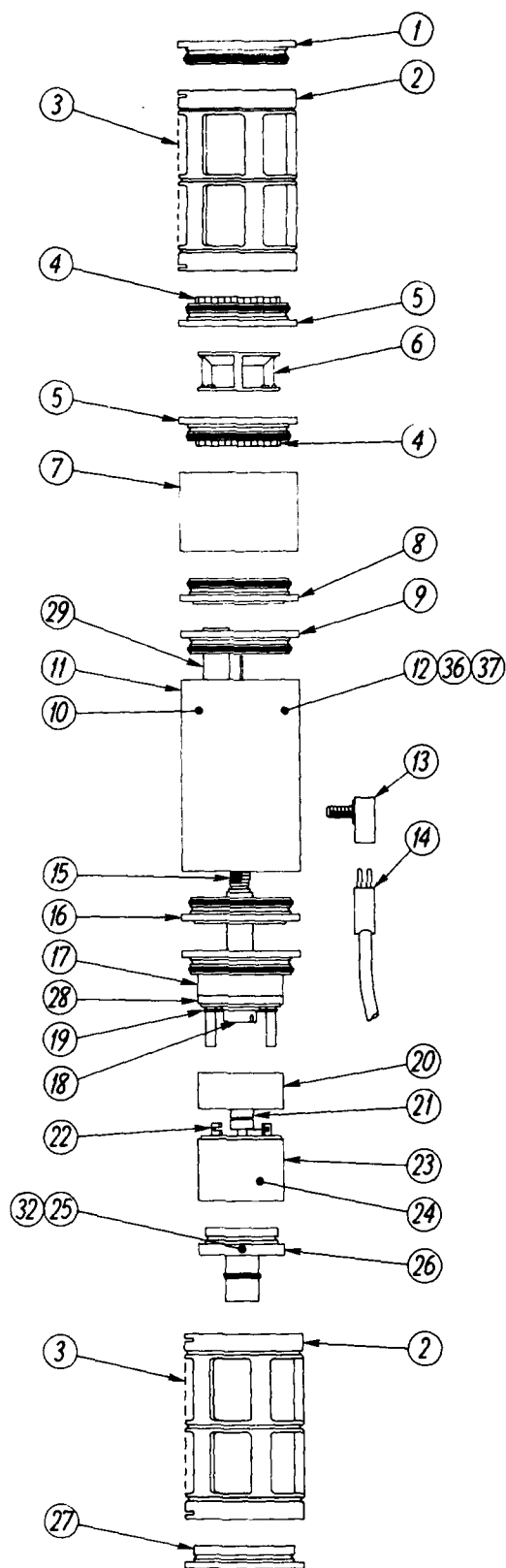


Figure 8. Exploded assembly drawing of the D10IQ.

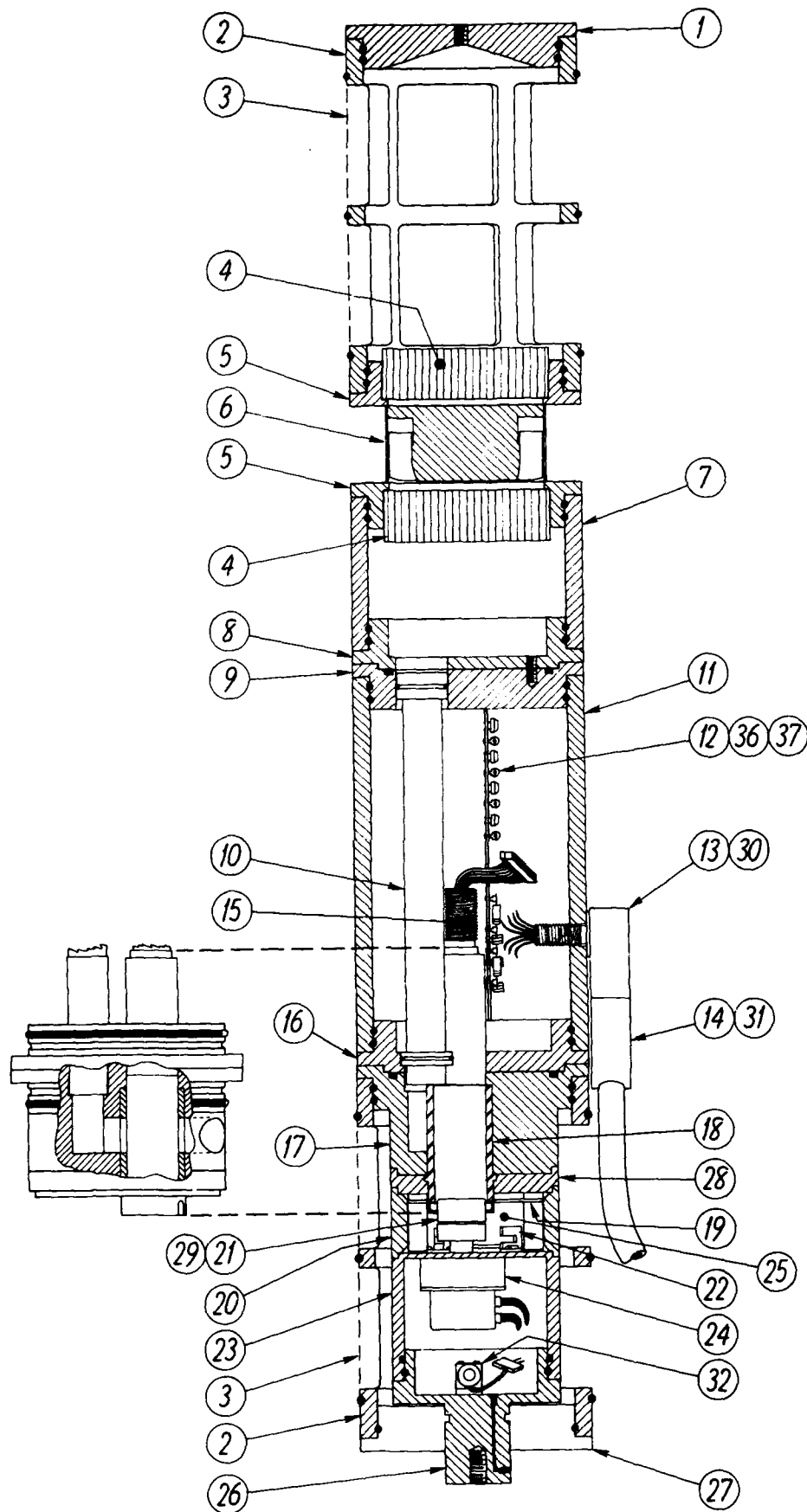


Figure 9. Exploded parts drawing of the D10IQ (drawing no. 198447.100).

is a commercially available unit (Tattletale IV) with on-board BASIC for ease of software modification (details in Appendix C). The software is freely available from the authors and is self documented well enough to be modifiable by programmers reasonably familiar with BASIC.

VI. Comments on the D10IQ Prototype

As the design was completed in 1987, it became clear that the final instrument configuration could be made only after extensive test experience. The present D10IQ has maintained great flexibility, but is more expensive than we believe is feasible for wide use, and more expensive than necessary. The cost for prototype units built one at a time is approximately \$3,200 for materials and about 300 hours of labor. Fabrication and deployment of a few of these instruments will permit the remaining design issues to be addressed based on field experience. It will then be possible to design a more easily produced and lower cost instrument.

We see the major, remaining design issues to be those involving the protection and cleaning of the mirror. Factors which may be important, and which we will be attempting to clarify in tests during 1988 and 1989, include the following:

1. Sequence and timing of the pacer cycle. If the major contaminant is deposited during the cooling phase of the measurement and pacer cycle, then excessive use of the pacer cycle might serve to hasten rather than delay fouling of the mirror. This is likely to be the case if fouling comes from hydrocarbon material rather than sea salt.

2. Filter porosity. The present filter porosity is 5 microns, which is somewhat larger than many of the particles that make up marine aerosol. It may be desirable to use smaller porosity which will tend to inhibit air flow. If sufficient aspiration pressure exists to achieve adequate air flow, then use of a tighter filter should tend to reduce fouling by aerosol particles.

3. Filter area. It is desirable to minimize the overall area of the instrument surface that is exposed to the sample air flow on the intake side of the instrument. This is important because salt deposition on the intake could lead to a biased

measurement by creating an inadvertent, saturated humidity cell (though we have never heard of this happening in practice). The only way we know to avoid this potential problem is to minimize the contact between the sample air and instrument surfaces. This is clearly at odds with having a filter on the intake.

4. Nitrogen jet. The nitrogen jet described above could prove useful as a cleaning or protective measure, though at some additional expense and overall complication of the design. The jet should be omitted unless some useful results can be demonstrated.

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Appendix A: Test Results from 1986

In this appendix we list portions of the data from the 1986 test of commercially available humidity sensors. The aim of these tests was to find which (if any) of the available sensors might suffice in long-term unattended use. Data are listed at hourly intervals for five hour segments separated by about 4 days (year day is the time variable listed in the first column). As the standard we planned to use an EG&G Dew Pointer (listed in the second column under EG&G; AH is absolute humidity in gm/kg), backed up with occasional spot measurement by a manually operated sling psychrometer. As the test progressed, it became apparent that our EG&G unit was unreliable, and we eventually had to discard it from the tests. The psychrometer data was not logged in the same data stream, so we do not show that data here. The sensors tested were three Rotronics solid state sensors (ROTA, ROTB, ROTC), three General Eastern model 850 solid state sensors (850A, 850B, 850C), and a General Eastern chilled mirror Dew-10 sensor (D10).

Based upon a comparison with the sling psychrometer data, and upon inspection of the data shown here, it can be seen that two of the three Rotronics sensors failed catastrophically (ROTA on or before day 241 and ROTB on or before day 270). One of the General Eastern 850 sensors failed outright (850A on day 245), but each of the three 850 sensors exhibited fairly severe calibration error when checked after the tests (errors in relative humidity in excess of 10 percent and in some cases much larger). Since there is no way known to monitor calibration drift on solid state sensors, we concluded that these sensors were not good candidates for long-term, unattended use on ships and buoys.

YEAR	DAY	EGG AH	ROTA AH	ROTB AH	ROTC AH	850A AH	850B AH	850C AH	D10 AH
230.70		17.54	16.64	17.93	17.79	4.36	17.01	17.37	17.55
230.74		17.54	16.05	17.23	17.16	4.27	16.50	17.05	17.30
230.78		17.51	16.12	18.21	17.33	4.53	16.81	17.35	17.57
230.83		17.47	16.36	17.62	17.17	4.92	16.94	17.32	17.55
230.87		17.44	16.04	18.12	17.16	4.98	17.14	17.50	17.27
234.69		13.13	11.88	13.55	13.13	9.15	12.83	13.12	13.52
234.73		13.15	11.79	13.81	13.34	8.90	12.83	13.15	13.75
234.77		12.90	11.37	13.31	13.16	9.94	12.59	12.86	13.32
234.81		13.66	11.68	13.21	13.06	10.14	12.30	12.79	12.91
234.85		14.13	12.04	13.65	13.94	9.73	12.63	12.99	13.11
241.69		6.10	.00	5.90	5.75	5.95	5.91	5.66	5.76
241.73		7.20	.00	6.78	6.81	6.57	6.29	6.41	5.88
241.77		8.05	.00	7.30	7.69	7.41	7.09	6.97	6.60
241.81		8.72	.00	8.19	8.03	7.82	7.62	7.66	7.28
241.86		8.25	.00	8.02	7.80	7.94	7.80	7.73	7.46
245.56		15.27	45.01	13.69	13.21	11.48	12.05	11.86	12.44
245.60		14.17	43.72	13.10	12.77	10.44	12.24	12.20	12.63
245.64		14.51	42.81	13.62	13.21	10.20	12.57	12.48	12.77
245.68		14.91	43.72	13.74	13.40	7.37	13.00	12.90	13.16
245.73		15.27	43.72	13.94	13.58	6.72	13.03	13.32	13.20
247.66		12.46	45.97	11.07	10.92	8.93	10.55	10.56	10.44
247.70		12.18	43.72	11.31	11.23	8.66	10.30	10.41	10.12
247.74		12.53	43.73	11.08	11.13	8.46	10.29	10.32	10.38
247.78		12.23	43.73	11.17	11.09	8.24	10.11	10.31	10.30
247.83		12.57	42.82	11.08	10.79	8.17	10.33	10.38	10.21

YEARDAY	EGG AH	ROTA AH	ROTB AH	ROTC AH	850A AH	850B AH	850C AH	D10 AH
256.44	9.39	43.75	8.32	8.08	4.86	8.01	7.29	8.07
256.49	9.13	43.75	8.49	8.34	5.09	8.08	7.48	7.98
256.53	9.87	43.75	8.95	8.50	5.24	8.41	7.91	8.33
256.57	9.88	43.75	8.59	8.34	5.37	8.27	7.74	8.17
256.61	12.16	43.39	8.53	8.10	5.46	8.24	7.61	8.15
260.53	7.82	44.61	6.72	6.70	6.18	6.60	5.87	6.47
260.57	7.59	43.69	6.63	6.33	6.12	6.38	5.81	6.41
260.61	9.91	43.70	6.68	6.50	6.29	6.44	5.93	6.49
260.65	8.04	44.06	6.56	6.38	6.09	6.29	5.95	6.44
260.69	8.94	44.99	7.50	7.42	7.22	7.12	6.88	7.00
265.51	11.98	43.71	10.36	10.09	9.75	9.64	9.26	10.08
265.55	11.08	44.64	9.13	8.90	8.81	8.60	8.54	9.02
265.59	13.98	43.72	9.49	9.43	9.07	9.08	8.94	9.33
265.63	11.67	44.64	9.59	9.52	9.00	8.94	8.88	9.18
265.67	11.97	43.72	9.77	9.48	8.94	9.08	8.94	9.06
270.50	7.65	43.37	3.55	6.09	3.57	5.93	5.36	5.97
270.55	8.73	44.66	3.80	6.33	3.75	6.10	5.56	6.24
270.59	8.07	43.73	4.06	6.66	4.29	6.42	5.94	6.34
270.63	7.86	43.37	3.03	6.45	4.10	6.42	5.79	6.34
270.67	8.10	43.73	2.49	6.23	4.19	6.14	5.66	6.04
275.21	17.00	42.86	1.01	12.76	8.71	11.94	11.86	12.77
275.25	17.00	42.50	.71	12.58	8.70	11.81	11.38	12.35
275.30	17.03	43.77	.45	12.61	8.52	11.81	11.75	12.56
275.34	16.28	43.40	.31	11.60	8.06	10.61	10.56	11.04
275.38	16.73	43.77	.85	11.78	9.34	10.89	11.13	11.28
280.68	6.38	43.73	.00	5.04	4.40	4.82	4.47	4.83
280.73	5.87	42.82	.00	4.87	4.35	4.77	4.27	4.66
280.77	5.87	42.47	.17	4.87	4.40	4.77	4.25	4.69
280.81	6.04	42.46	.16	5.11	4.79	4.97	4.54	4.82
280.85	6.02	42.46	.00	4.84	4.40	4.82	4.36	4.68

Appendix B: Fabrication Information for the D10IQ

The Assembly Drawing Parts List shows the parts that are indexed on the assembly drawing (198447.100, Figure 9). There is a 'make' and/or 'buy' indication on each item. For the make items, separate drawings are provided. The buy items are listed by item number on the Purchase Parts List. Substitutions can certainly be made as long as mechanical fit is compatible. Some items, such as the main printed circuit board #1, are key components, as are the Dew-10 sensor head, seal drive motor and Tattletale computer. Miscellaneous parts such as bolts, nuts, screws, small spacers etc. have not been itemized. The internal interconnection uses ribbon cable and 0.100 inch flat flex connectors from DuPont Electronics. The 65801-female and the 66226-male part numbers are recommended. The printed circuit boards PC-2 and PC-3 have the 2x layout provided so that boards may be readily made. The main assembly drawing and the various subassembly drawings provide information on the various sections. The modular sections fasten together with splines which make maintenance very simple. The Tattletale plugs into the main printed circuit board which is set up at the factory for proper operation with the sensor.

Mechanical Features

Refer to the D10IQ photograph (Figure 7) and the assembly drawings (Figures 8 and 9). The body of the D10IQ is made of PVC in a modular construction. Each section is sealed with an O-ring and a locking spline. The locking spline is inserted on the outside of the O-ring through a slot and is positioned half in the sleeve and half in the plug, thereby locking the two together. Disassembly is accomplished by just pulling the locking spline out and pulling the sections apart. This permits easy modifications to any part of the unit without major rework and is in keeping with the goal of flexible design.

Gore-Tex Filters. Each end of the unit has a Gore-Tex 5 micron filter held in place with O-rings. The area of each filter is about 47 square inches which maximizes air flow.

Fan and Flow Straightener. A brushless DC fan is used to provide aspiration for the unit. A honeycomb unit is placed on both sides of the fan to straighten the air flow. This fan is controlled by the main printed circuit card #1 controller and provides about 3 to 5 cubic feet per hour of air flow. This is the maximum flow rate that still permits the electric cooler in the dew point sensor head to maintain control. A higher flow rate results in excessive cooling.

Sensor Closure Mechanism. The sensor head is held in a rotating sleeve that seals the head from the environment when in its closed position. When rotated 90 degrees, it lines up with the aspiration tube and permits air to flow past the sensor. The sensor is just inside the tube and close to the filter thereby minimizing the dead air that must be removed when the aspiration starts. The sleeve is driven by a stepper motor and stepper motor electronics. The motor and electronics are housed in a PVC section that is inside the lower filter section. There are also LED switch limit stops to insure proper alignment.

N₂ Valve. Below the stepper motor is a small N₂ valve that directs a jet of dry nitrogen to the sensor head. Nitrogen is piped in at the bottom of the unit using micro-fittings and can be up to 100 psi.

Electronics and Sensor Head Housing. The electronics and sensor head are housed in a sealed section that has a bypass tube for the air sample to be pulled through the chamber without being in contact with the electronics. The main printed circuit board is manufactured by General Eastern Instruments Corp. as a custom but commercially available unit. The Tattletale IV microcomputer plugs into this main board. These boards are held in a bracket within this section. The underwater bulkhead connectors permit the system and UART wiring to come into the electronics and be sealed from the environment.

Electronics Features

Refer to the D10IQ Cable Diagram (198447.200) for a description of the electronics in the instrument. The system data logger interfaces with the unit via a 7-pin male underwater bulkhead connector. The wires include +12 volts DC, ground, Serial Data Out (5 volts ASCII), and the *DTR Data Request line that is

normally at +5 volts DC and requests data with a momentary low. The system can be monitored by a computer via the UART connection which comes into the unit with a 7-pin female underwater bulkhead connector. The main printed circuit board contains all of the sensor interface and control electronics as well as the drivers for the fan, seal motor and N₂ valve. The microcomputer, a Tattletale IV, also plugs into the main board. The seal motor, seal electronics, limit stop electronics and N₂ valve are located below the main board. The sensor head interfaces to the main board through a ribbon cable/connector.

D10IQ Assembly Drawing Parts List

		Make or Buy
101.	Top End Cap	M
102.	Gore-Tex Filter Shell, inlet and discharge	M
103.	Gore-Tex Filter Sheet	B
104.	Honeycomb Fan Flow Straightener	B/M
105.	Fan Mounting Flange	M
106.	Fan	B
107.	Fan Plenum Chamber Shell	M
108.	Intermediate Adapter-Fan Plenum	M
109.	Intermediate Adapter-Electronics Package	M
110.	Heater Chimney	M
111.	D-10 Convection Tube and Electronics Housing	M
112.	P.C. Board #1	B
113.	UW Bulkhead Connector-System	B
114.	UW Mating Connector-System	B
115.	Dew-10 Sensor Head	B
116.	Intermediate Adapter Sensor Head Base	M
117A.	D-10 Sensor and Convector Tube Base	M
117B.	117A Bottom View	M
117C.	Duckbill Valve Assembly	M
118.	D-10 Closure Plug	M
119.	P.C. Board #2, Seal	B/M
120.	Closure Plug Optical Interrupt Position Sensor Housing	M
121A.	Optical Switch Zero Adjustment Vane	M
121B.	Sleeve Valve Drive Coupling and Spring Sleeve	M
122.	P.C. Board #3 Limit Stop Electronics	B/M
123.	D-10 Closure Plug-Motor Drive Housing	M
124.	Seal Drive Motor	B
125.	Seal Electronics P.C. Assembly	B/M
126.	Drive Housing End Plug with N ₂ Inlet Port	M
127.	Bottom End Cap	M
128.	Plug Retainer Plate	M
129.	Layout of D-10 Sleeve Valve Closure Mechanism	M
130.	UW Bulkhead Connector-UART	B
131.	UW Mating Connector-UART	B
132.	N ₂ Valve	B
133.	Gore-Tex O-Rings	B
134.	Main Body O-Rings	B
135.	Locking Splines	B
136A.	PC-2 Mounting Bracket Parts	M
136B.	PC-2 Mounting Bracket Assembly	M
137.	Tattletale IV Microcomputer	B

Note: The part number is 100 greater than the label on the drawings, Figures 8 and 9, i.e. part no. 101 is ①.

D10IQ Purchase Parts List

103. Gore-Tex Filter Sheet

Gore-Tex membrane, non-woven polyester backing.

Nominal 5 micron. 8" x 15". 2 sheets.

W. L. Gore & Associates, Inc., Membrane Products Division

100 Airport Road, Post Office Box 1550, Elkton, Maryland 21921

Estimated Cost for 2 sheets: \$63

104. Honeycomb Fan Flow Straightener

2 sections 4" dia x 2" long honeycomb/fiberglass with nominal

3/8" hexagonal cells. HRA - 10 gauge 210

Hexcel Corporation

St. Clair Industrial Park

Post Office Box 179, Pottsville, Pennsylvania 17901

106. Fan

Model 159DH 1LP 31000

12 volts DC, 2.2 watts, 0.18 amps, 3600 rpm, 29 CFM.

3.125" x 3.125" x 1.25", 7 oz. ball bearings.

ETRI Corporation

608 Broome Street, Monroe, North Carolina 28110

(704) 289-5423

112. P.C. Board #1

PN 4008-1762 Chilled Mirror Hygrometer Controller Board

General Eastern Instruments Corporation

50 Hunt Street, Watertown, Massachusetts 02172

(617) 923-2386

Attn: Sumner Weisman

Estimated cost: \$1050

113. UW Bulkhead Connector-System

PN LPBH7M 7 pin male bulkhead connector

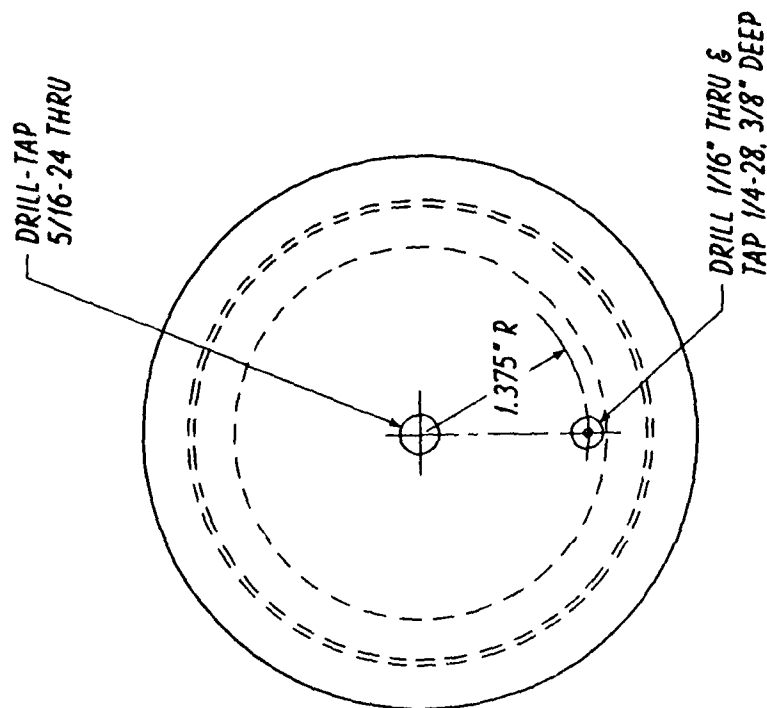
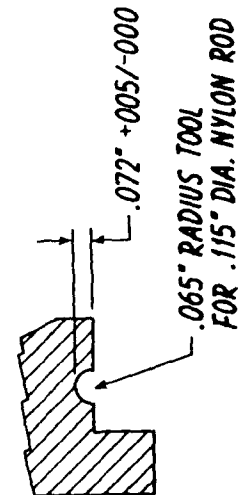
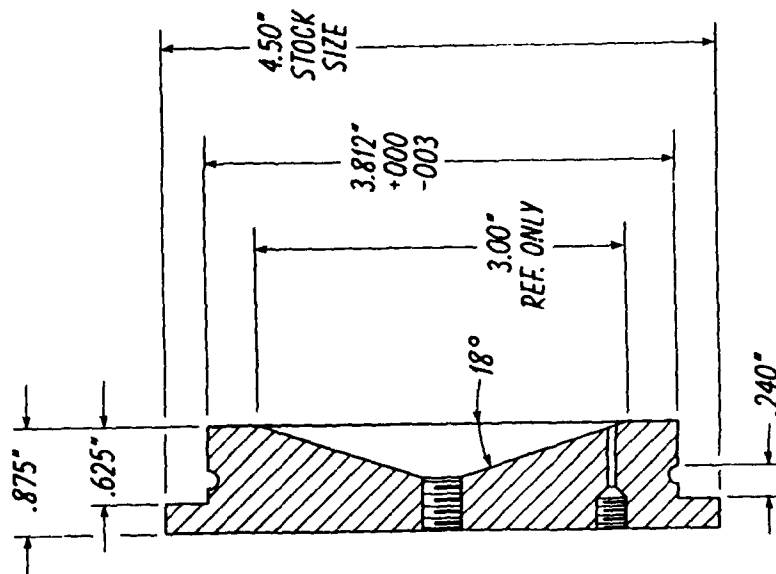
Impulse Enterprise

8274 Ronson Road, San Diego, California 92111

(619) 565-7050

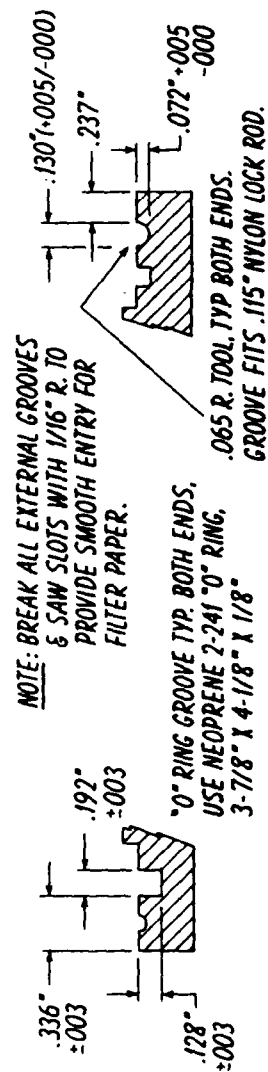
Estimated Cost: \$65

114. UW Mating Connector-System
PN LP1L7F 7 pin female cable connector
Impulse Enterprise
Estimated Cost: \$45
115. DEW-10 Sensor Head
PN 4005-0254, Dew Point Sensor
General Eastern Instruments Corporation
Estimated Cost: \$395
124. Seal Drive Motor
PN K2439-P2. AIRPAX Stepper motor, 75:1 gear ratio, 12 V DC,
pulse rate 157/sec. Use SAA -1027 drive chip.
Selmark Inc.
Post Office Box 68, Millis, Massachusetts 02054
(508) 376-2914
Estimated Cost: \$50 motor, \$20 chip.
130. UW Bulkhead Connector-UART
PN LPBH7F 7 pin female bulkhead connector
Impulse Enterprise
Estimated Cost: \$70
131. UW Mating Connector-UART
PN LP1L7M 7 pin male cable connector
Impulse Enterprise
Estimated Cost: \$40
132. N₂ Valve
PN LFHA 1200160M 12 V DC. High pressure valve for nitrogen service.
The Lee Company
2 Pettipaug Road, Westbrook, Connecticut 06498
(203) 399-6281
137. Tattletale IV Microcomputer
Tattletale 4 Development Kit
Onset Computers Corporation
Post Office Box 1016, North Falmouth, Massachusetts 02556
Estimated Cost: \$490



TOP END CAP
198447.101

MATERIAL: PVC
QTY. REQUIRED: 1 PIECE



GORTEX FILTER SHELL, INLET AND
DISCHARGE SECTIONS - 198447.102

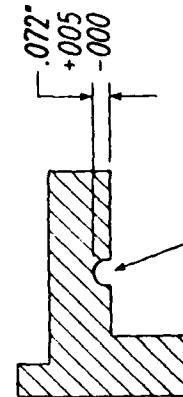
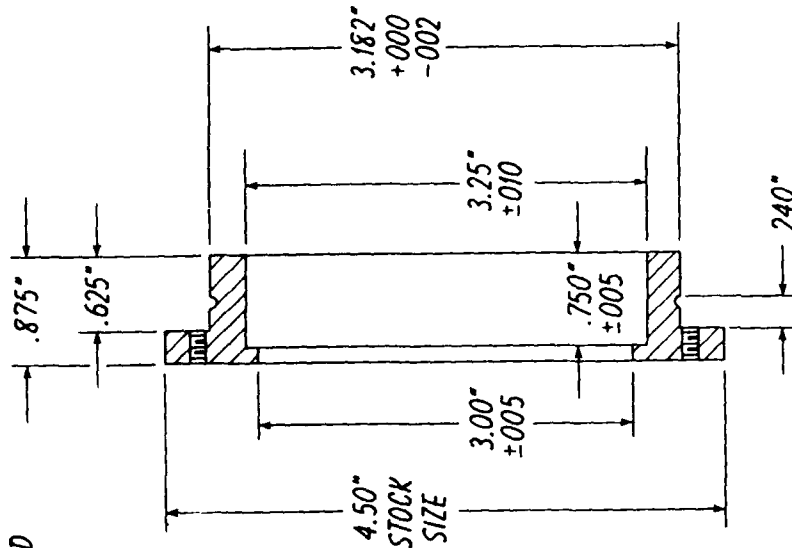
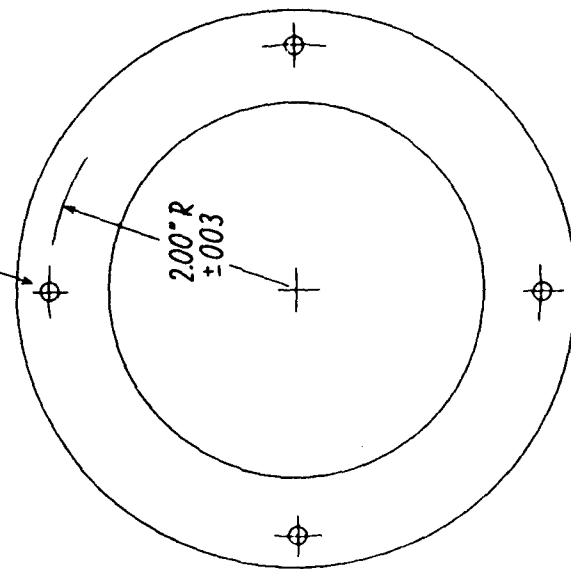
**MATERIAL: SCHEDULE 80 PVC PIPE
4.5" O.D. X 3.786" I.D.**

QTY. REQUIRED: 2 PIECES



Honeycomb Fan flow
Straightener
Part no. 104

DRILL-TAP 4 EQUALLY SPACED
HOLES, 8-32 TAP AND DRILL,
BREAK-THRU ACCEPTABLE



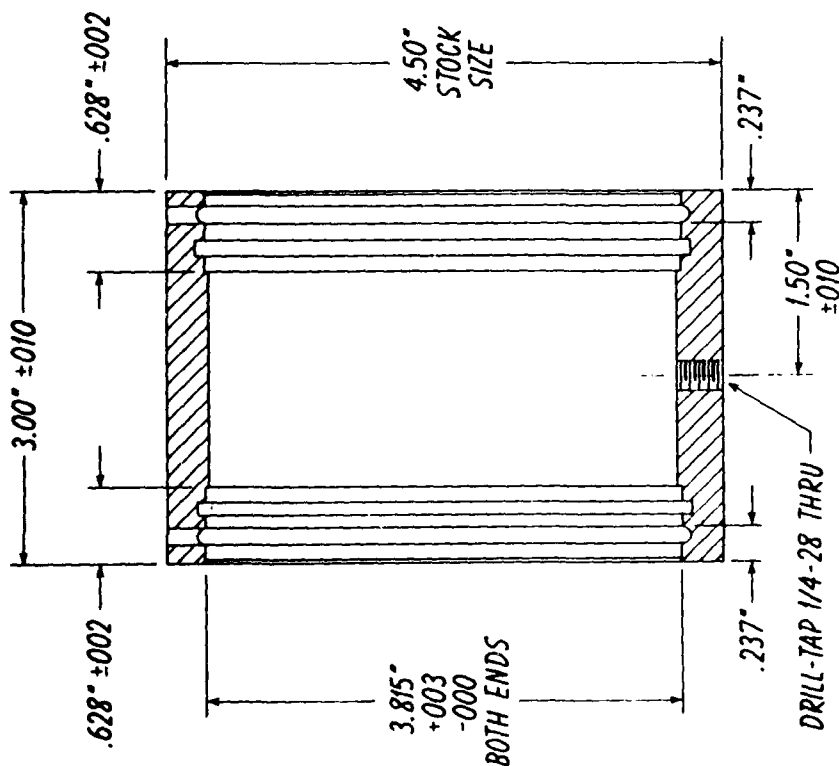
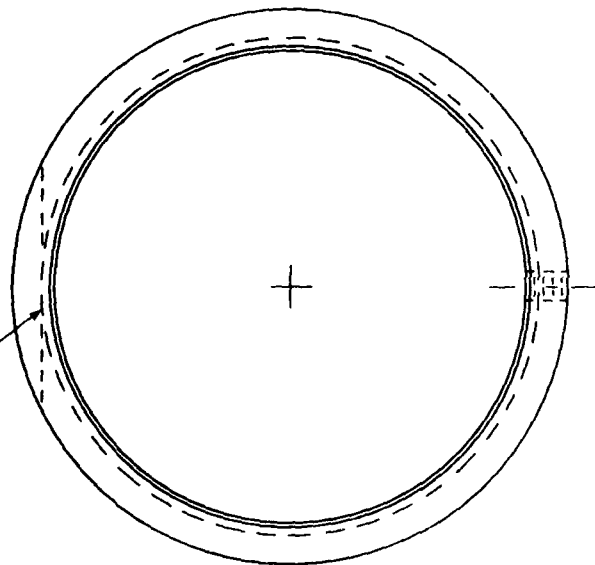
FAN MOUNTING FLANGE

198447.105

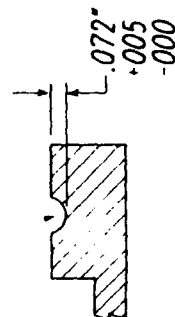
MATERIAL: 4-1/2" PVC SOLID ROUND STOCK
QTY. REQUIRED: 2 PIECES

.065" R TOOL
FOR .115" DIA. NYLON ROD

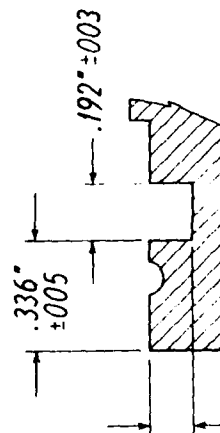
MACHINE TO INTERSECT INTERNAL GROOVE.
USE 7/64" SAW, SLOT 1 PLACE EA. END ON
DIA., DEPTH TANGENT TO 3.815" I.D. $+0.010$
 -0.000



.065" RADIUS TOOL
FOR .115" DIA. NYLON ROD



"O" RING & LOCK RING
GROOVES TYPICAL AT
BOTH ENDS



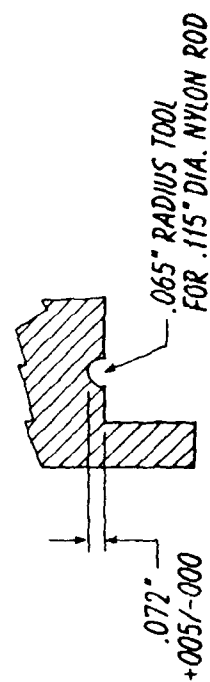
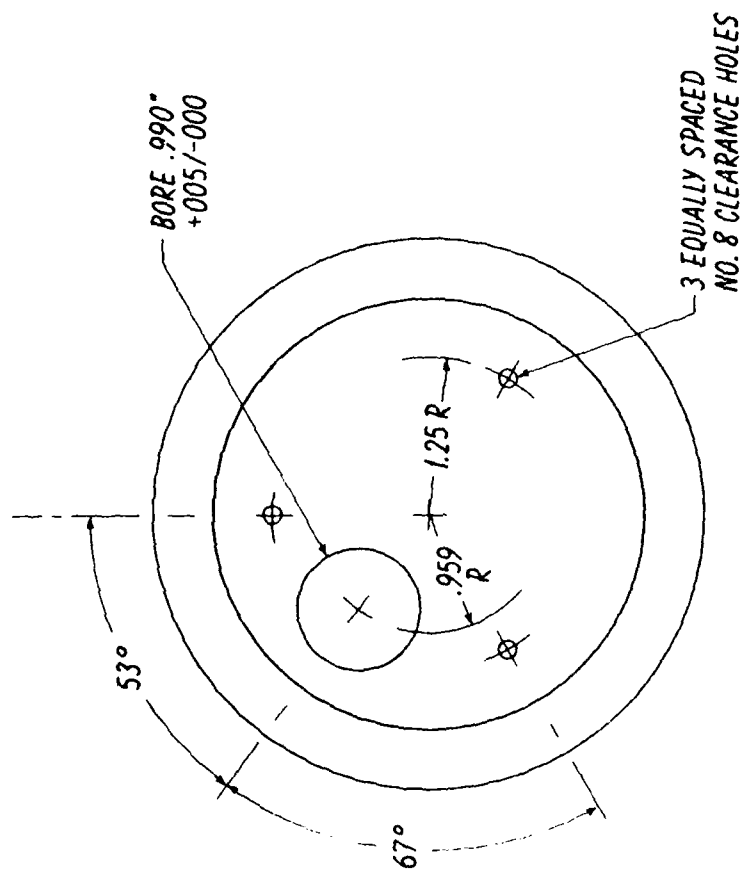
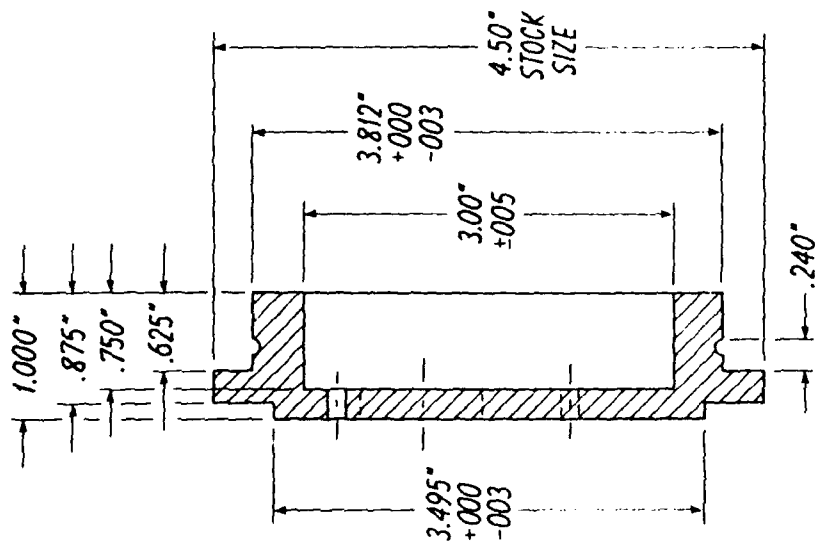
USE NEOPRENE "O" RING 2-241.
3-7/8" X 4-1/8" X 1/8" WALL

FAN PLENUM
CHAMBER SHELL

198447.107

MATERIAL: SCHEDULE 80
PVC PIPE

QTY. REQUIRED: 1 PIECE



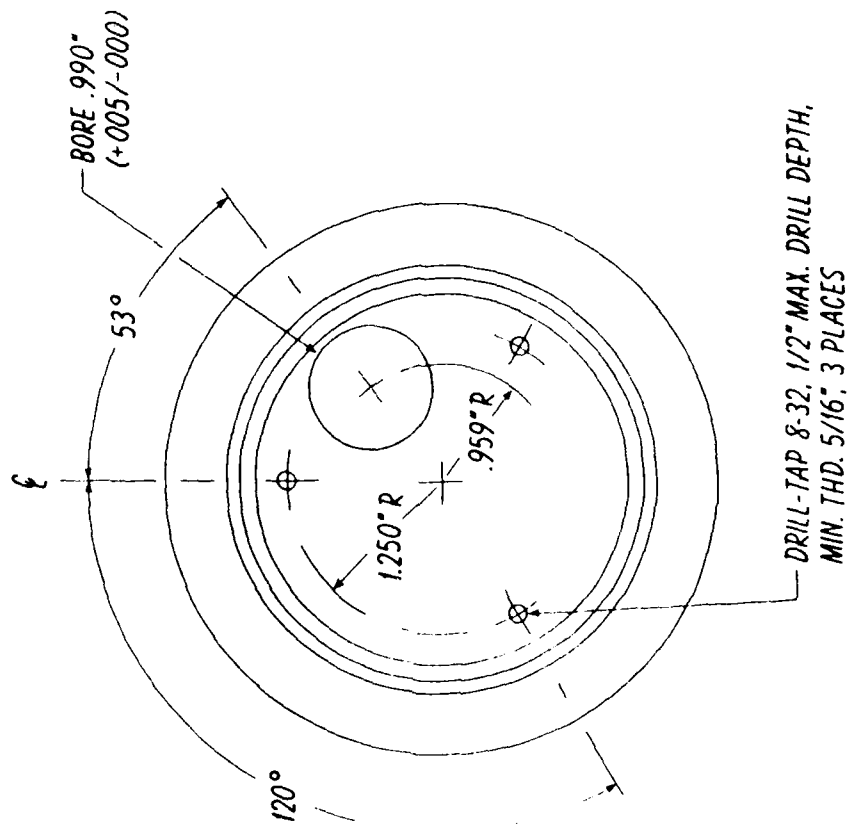
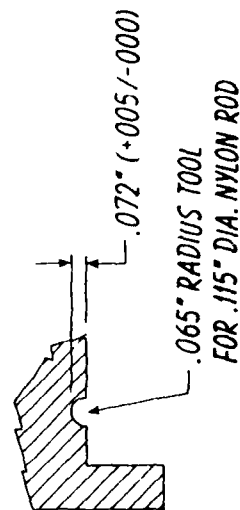
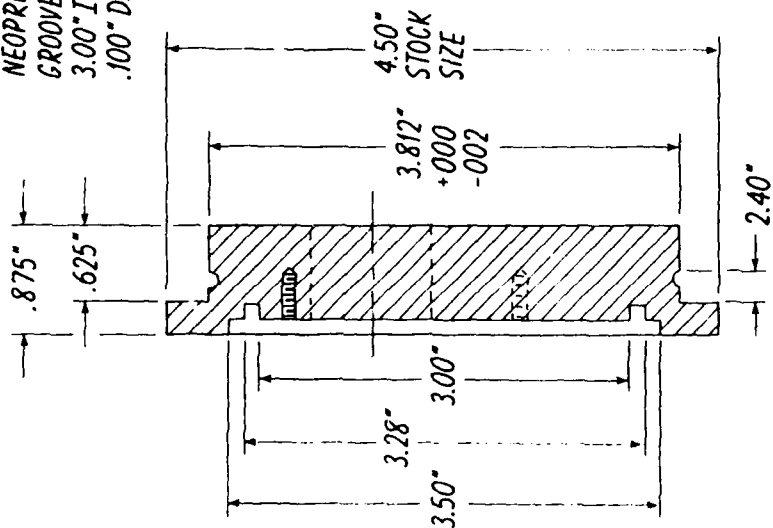
INTERMEDIATE ADAPTER - FAN PLENUM

198447.108

MATERIAL: PVC

QTY. REQUIRED: 1 PIECE

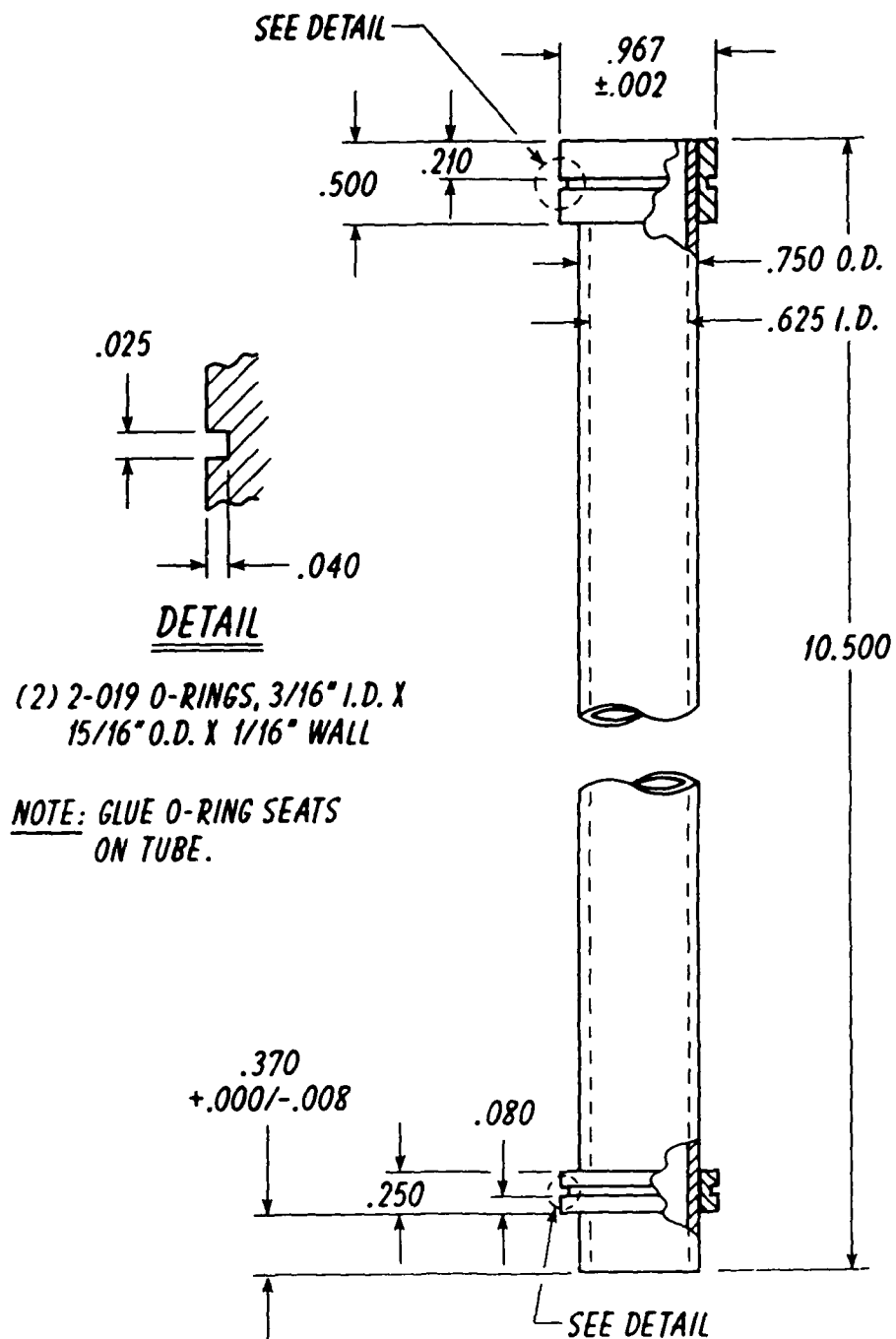
NEOPRENE "O" RING 2-151
GROOVE DIMENSIONS:
3.00" I.D. X 3.280" O.D. X
.100" DEPTH



INTERMEDIATE ADAPTER - ELECTRONICS PACKAGE

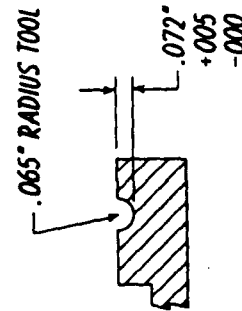
198447.109

MATERIAL: PVC, QTY. REQUIRED: 1 PIECE



MATERIAL: FIBERGLASS G10
QTY. REQUIRED: 1 PIECE

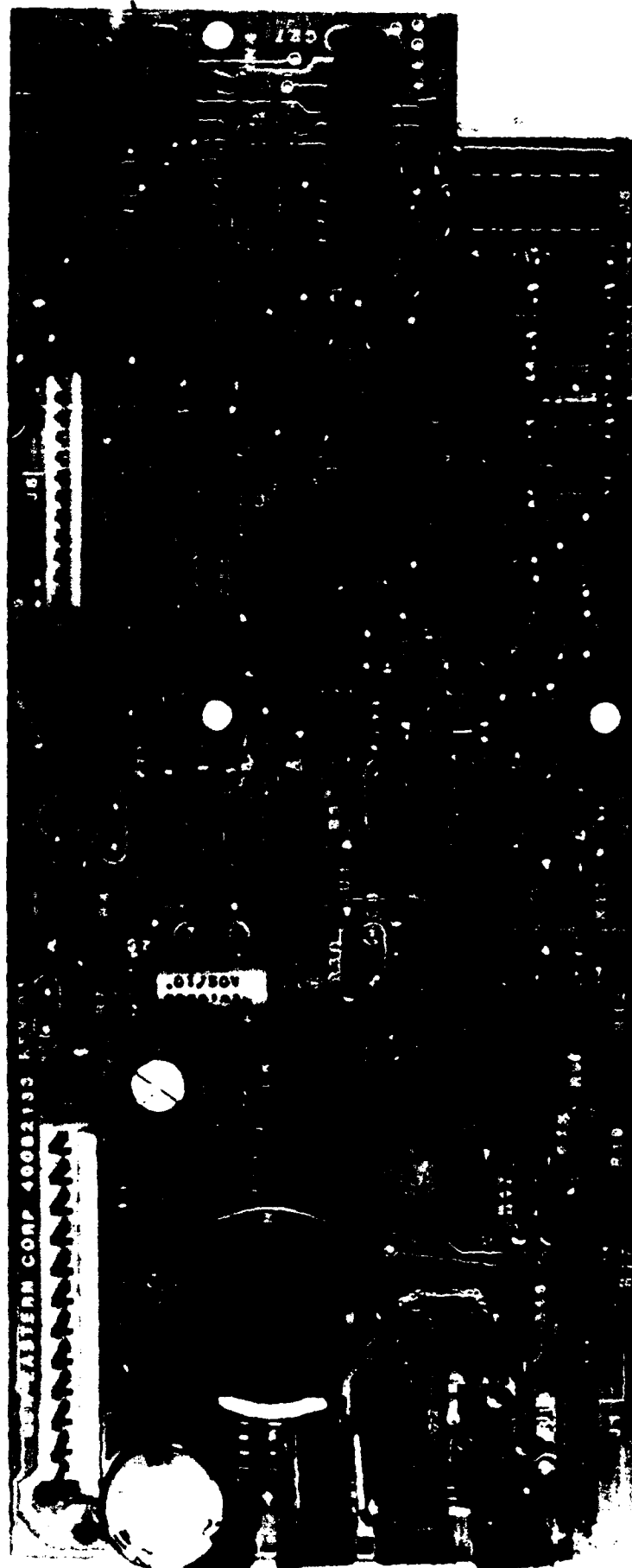
CONVECTION TUBE
198447.110



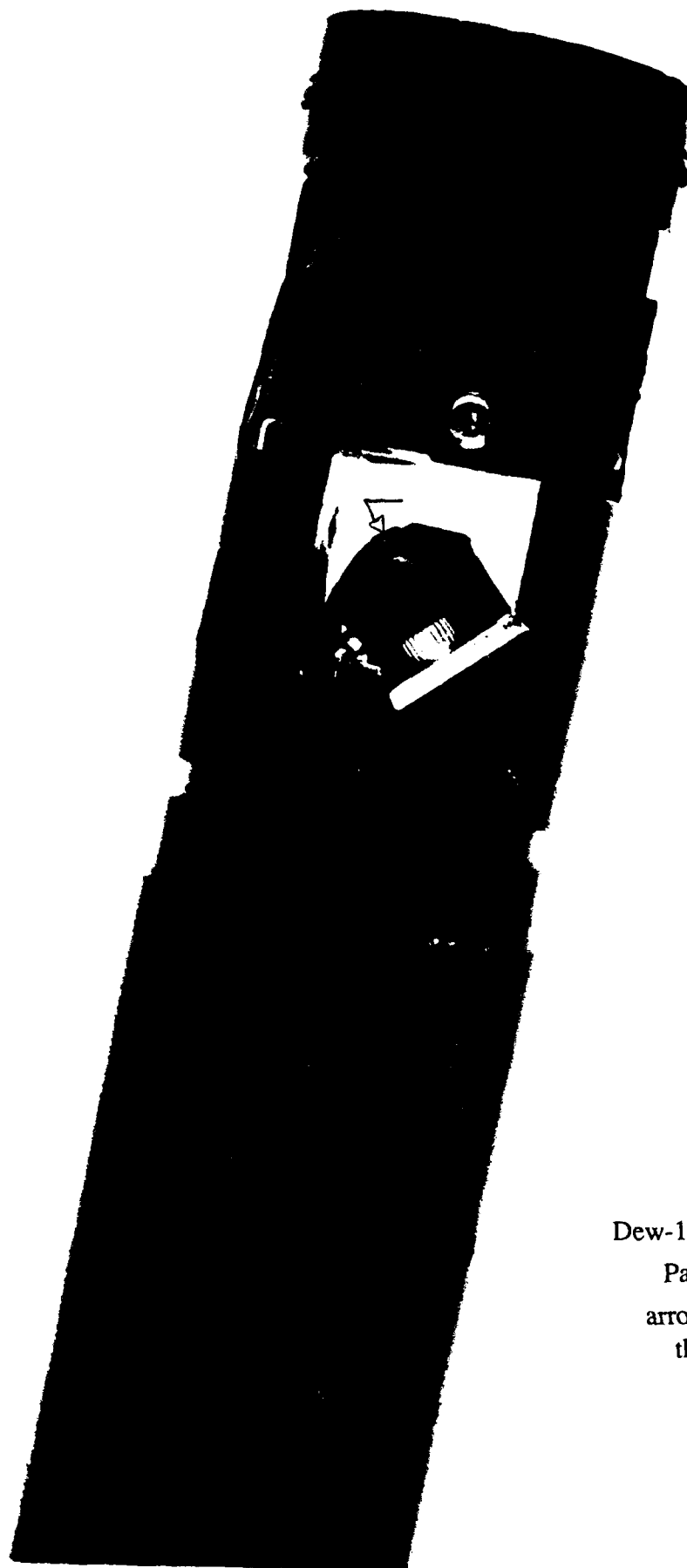
**"O" RING & LOCK RING
GROOVES TYPICAL AT
BOTH ENDS**

USE NEOPRENE "O" RING 2-241,
3-7/8" X 4-1/8" X 1/8" WALL

MATERIAL: SCHEDULE 80 PVC PIPE
QTY. REQUIRED: 1 PIECE



P.C. Board #1
Part no. 112



Dew-10 Sensor Head

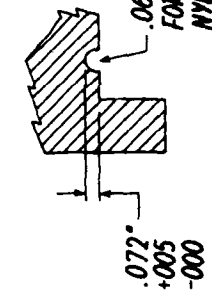
Part no. 115

arrow indicates
the mirror



198447.116

MATERIAL: PVC, QTY. REQUIRED: 1 PIECE



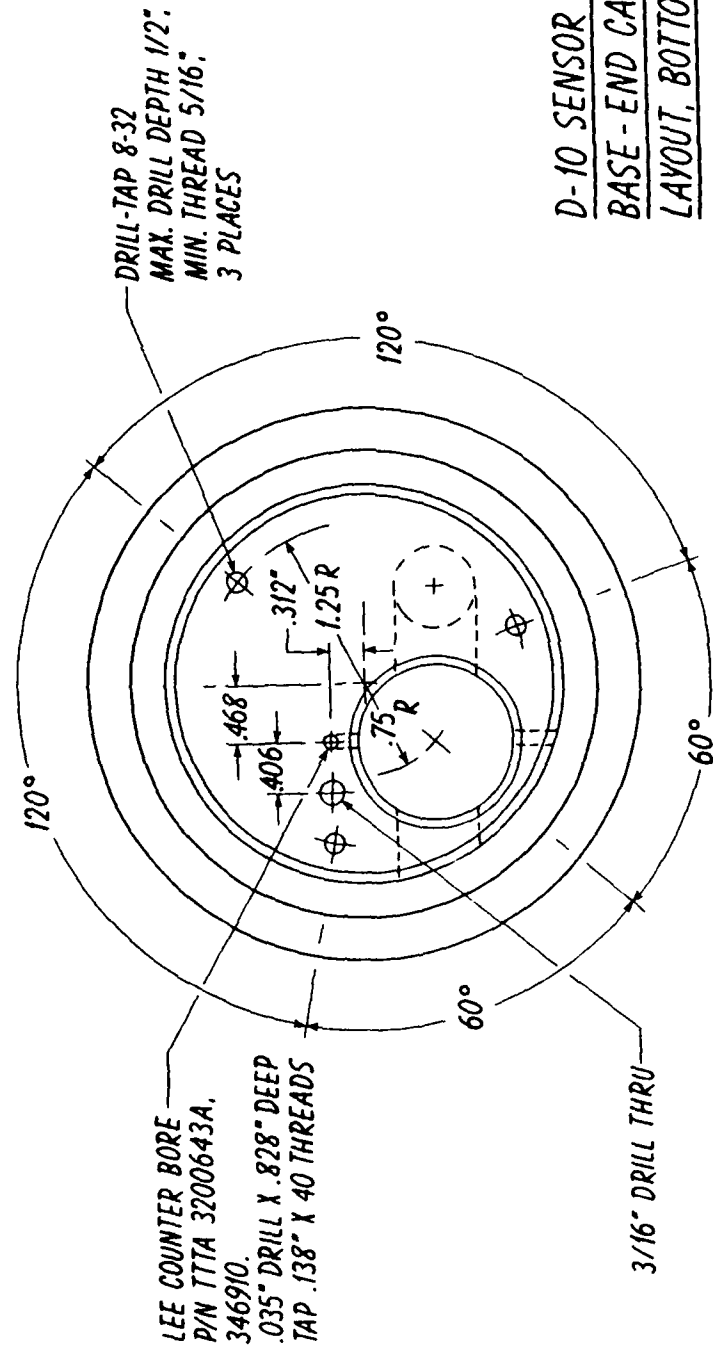
**2-151 2" O.D. X 3.28" O.D. X .10" DP.
GROOVE DIMENSIONS:**

**.065" RADIUS TOOL
FOR .115" DIA.
NYLON ROD**

D-10 SENSOR & CONVECTOR TUBE BASE
198447.117A

**MATERIAL: PVC; QTY. REQUIRED: 1 PIECE
FOR BOTTOM VIEW, SEE DWG. NO. 198447.117 B**

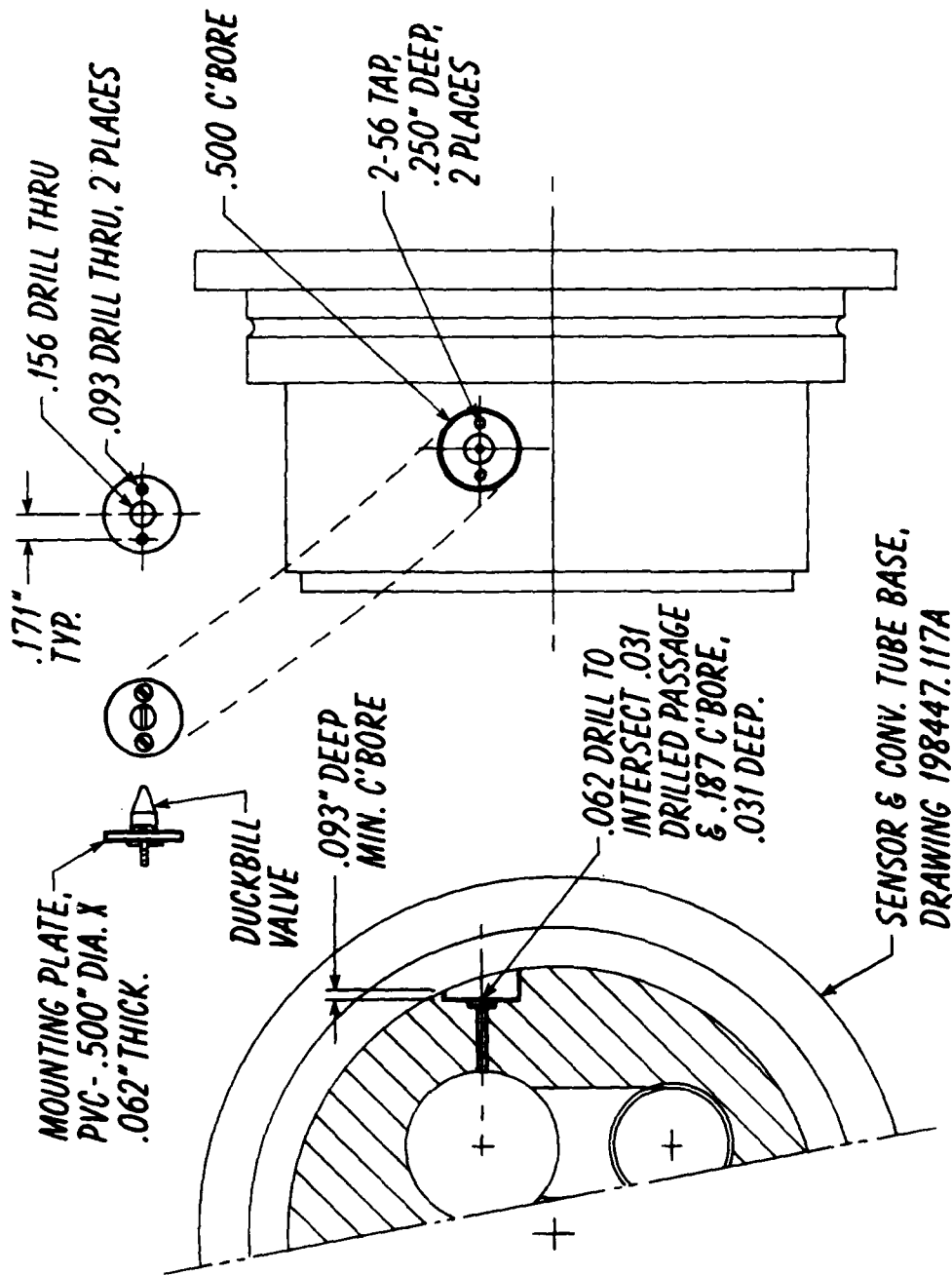




D-10 SENSOR & CONNECTOR TUBE
BASE - END CAP MOUNTING HOLE
LAYOUT, BOTTOM VIEW

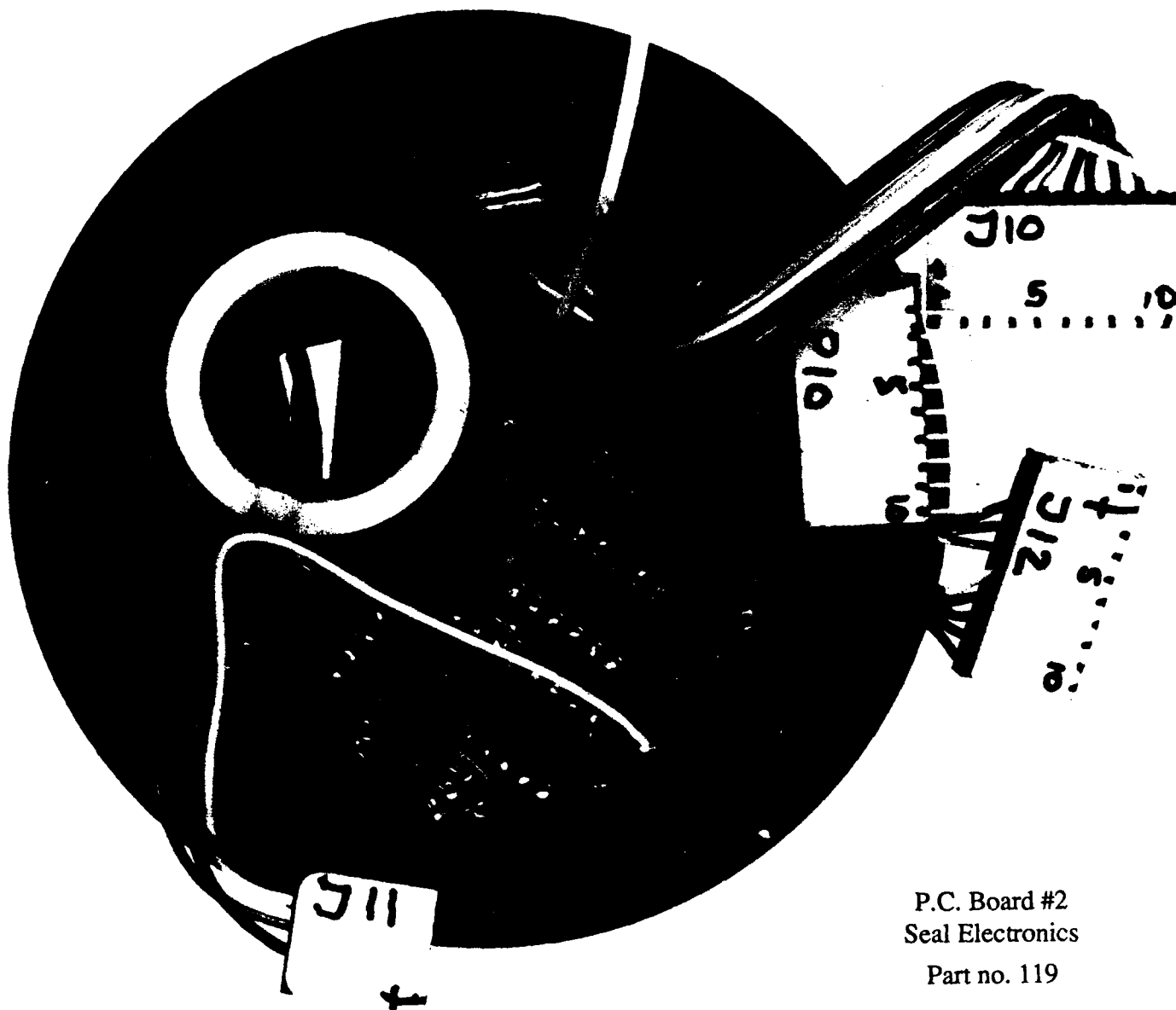
198447.117 B

FOR BASE TOP VIEW, SEE DRAWING NO.
198447.117 A

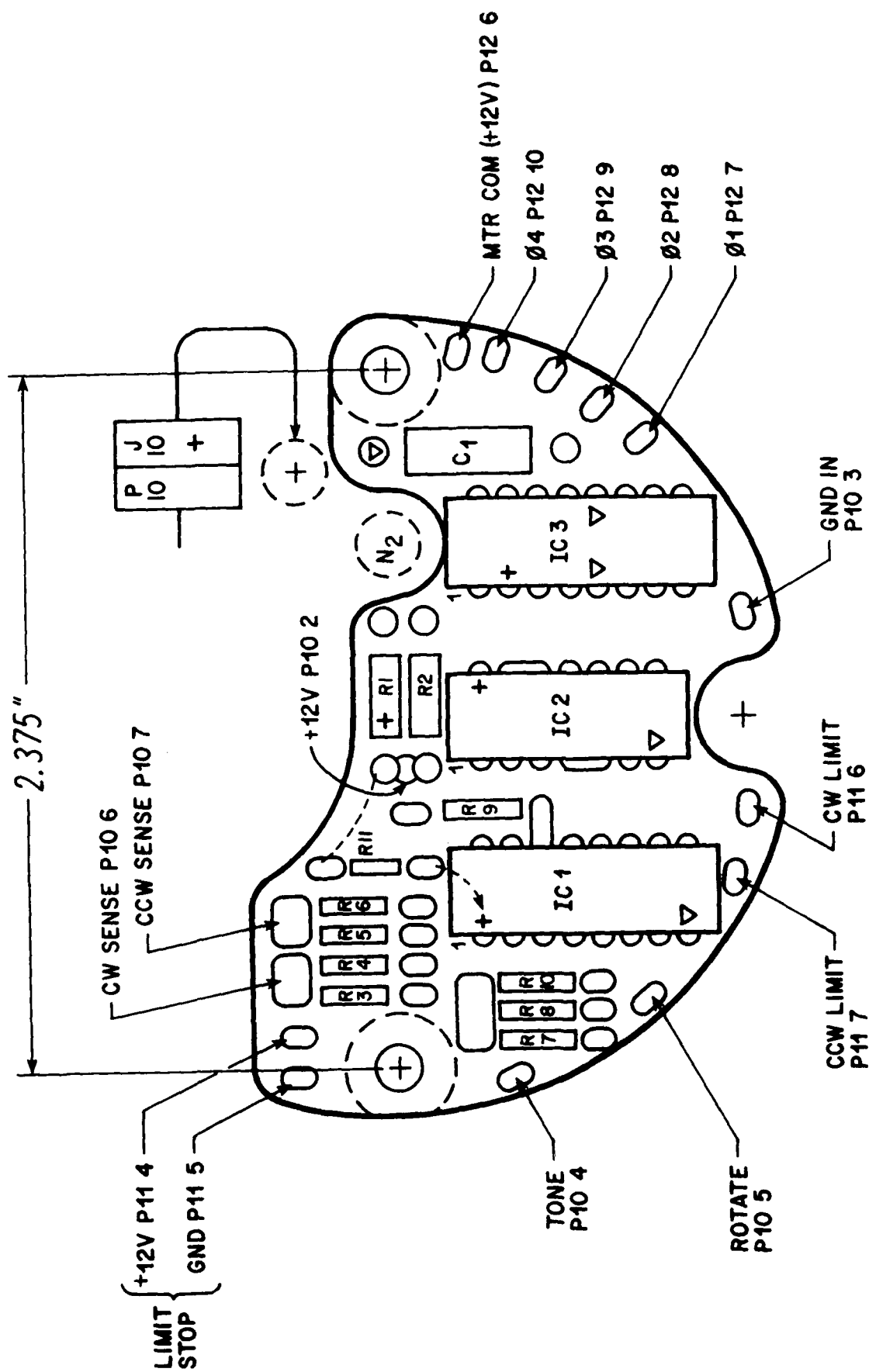


DUCKBILL VALVE:
VERNAV PART NO. VA3168

DUCKBILL VALVE
ASSY. & PLACEMENT
198447.117C

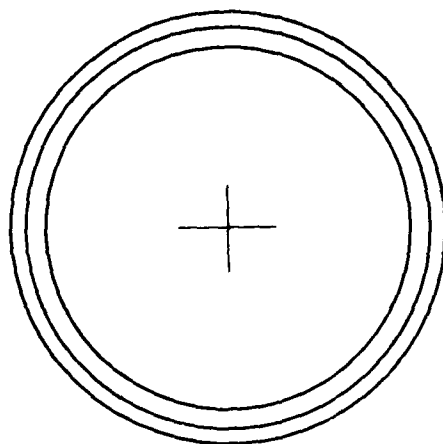
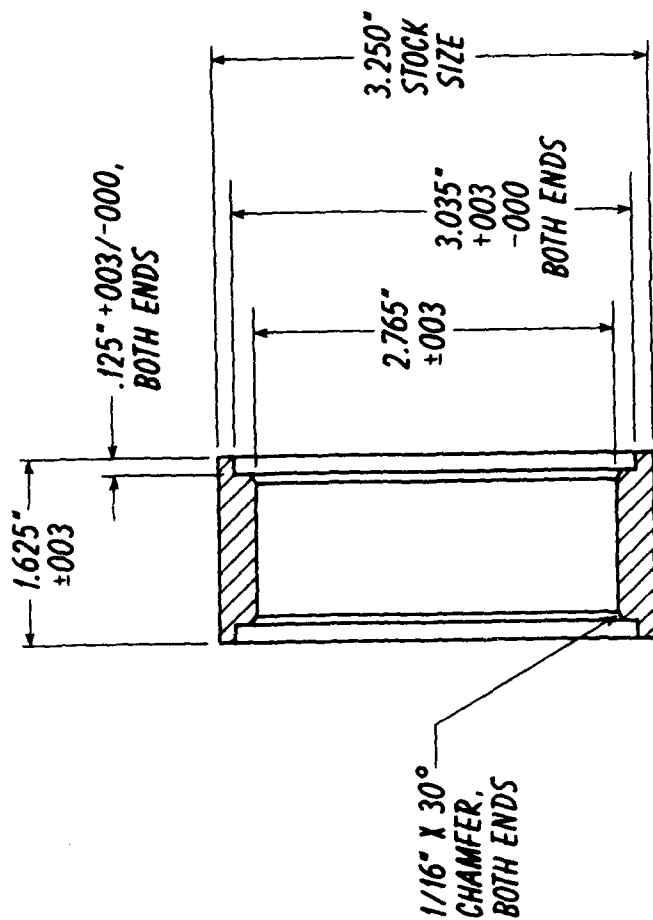


P.C. Board #2
 Seal Electronics
 Part no. 119



(PC-2) SEAL BOARD LAYOUT
198447.119

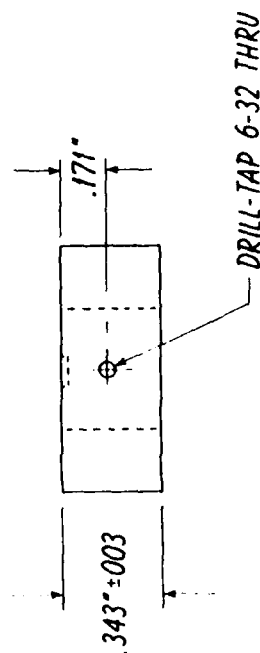
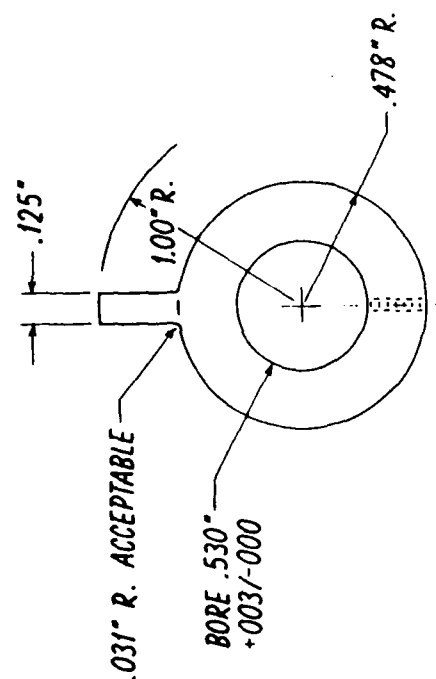
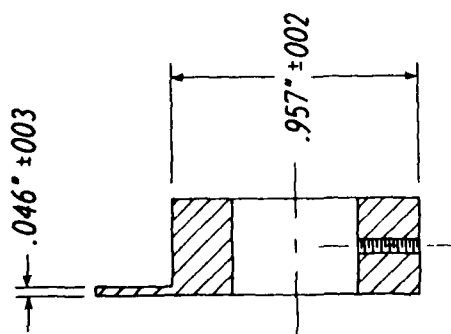
NOTE:
Add R11 between +12V & Pin 1 of IC1.



D-10 CLOSURE PLUG OPTO INTERRUPT
POSITION SENSOR HOUSING

198447.120

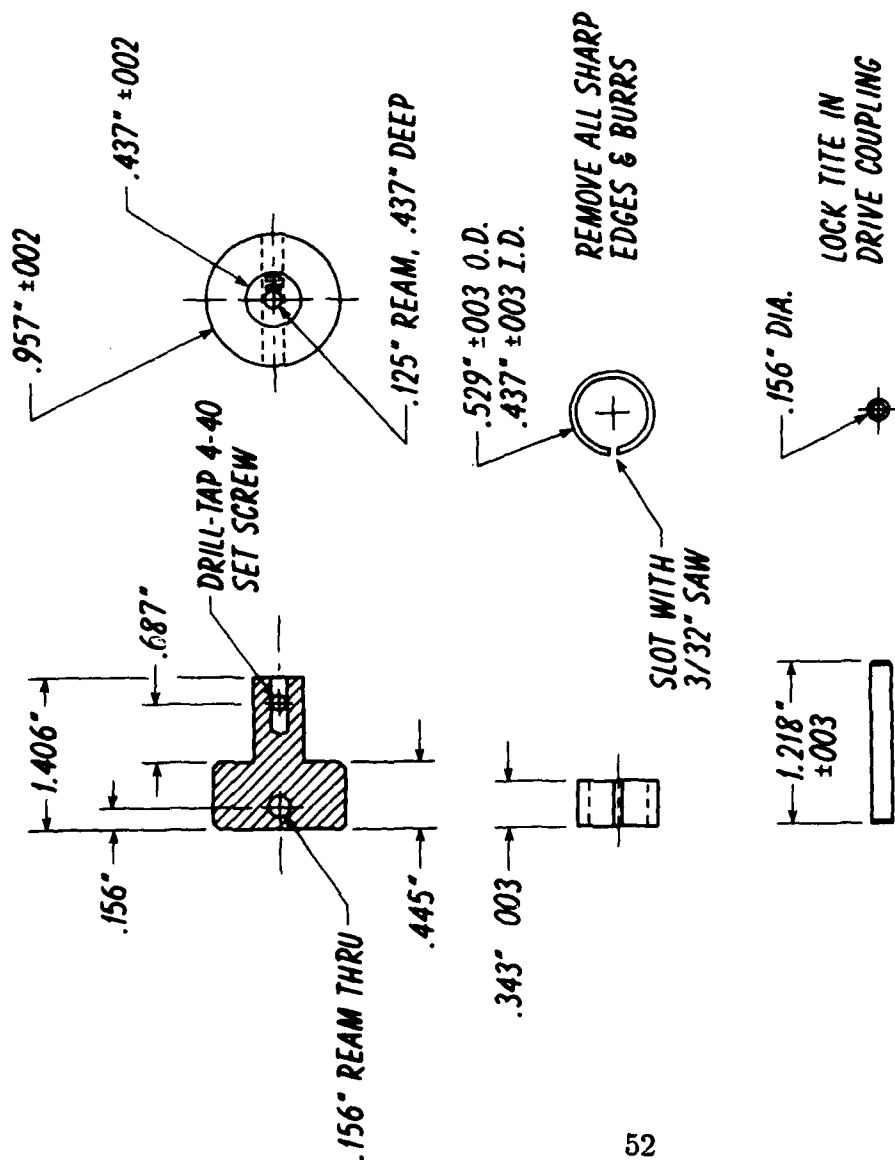
MATERIAL: PVC ROD OR HEAVY WALL TUBE
QTY. REQUIRED: 1 PIECE



OPTICAL SWITCH ZERO ADJUSTMENT VANE

198447.121A

MATERIAL: 6061-T6 ALUMINUM ROD
QTY. REQUIRED: 1 PIECE



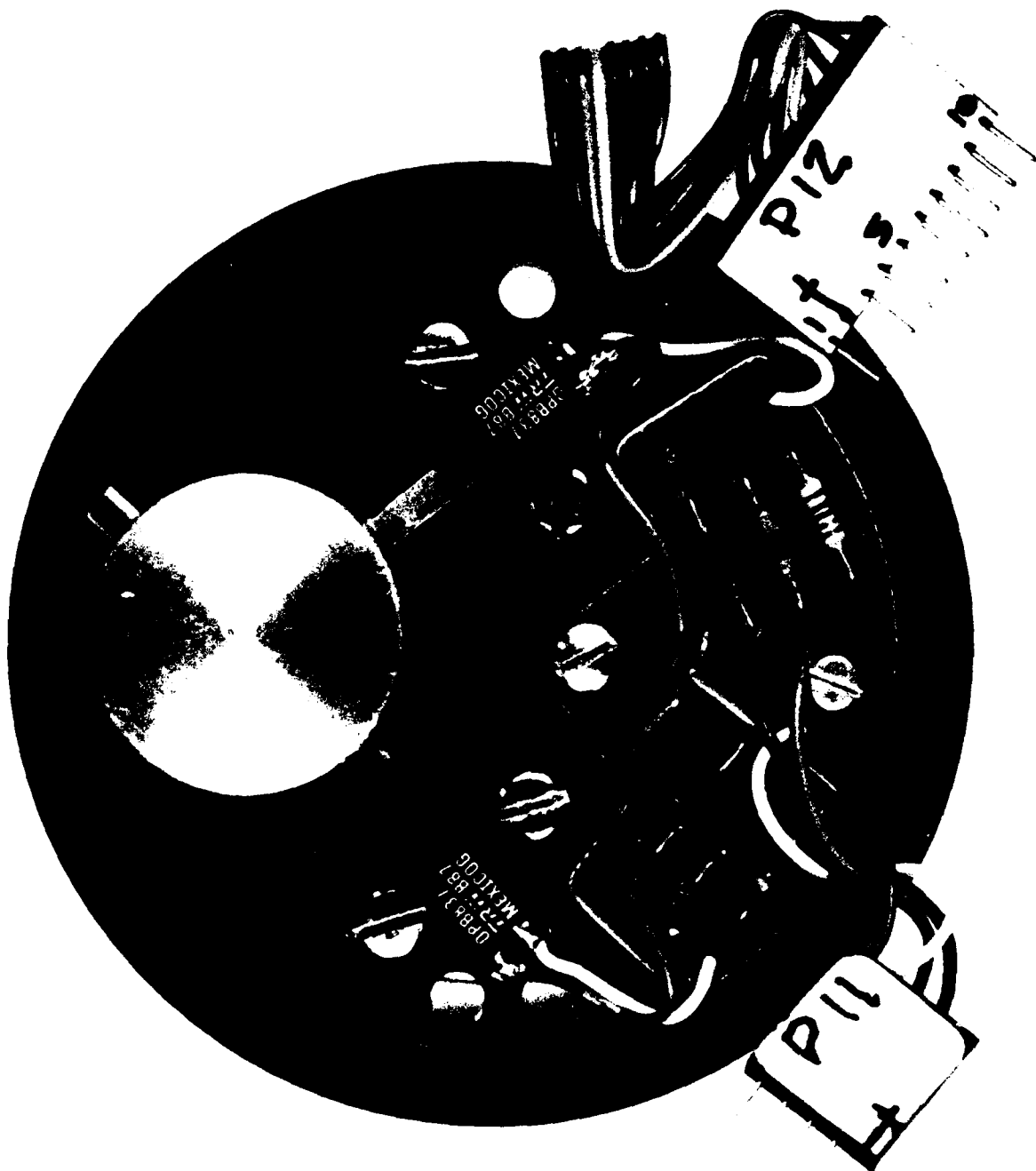
DRIVE COUPLING
 MATERIAL: 6061-T6 ALUMINUM
 QTY. REQUIRED: 1 PIECE

SPLIT RING LOCKING CLAMP
 MATERIAL: 300 SERIES ST. STEEL
 QTY. REQUIRED: 1 PIECE

SLEEVE VALVE DRIVE PIN
 MATERIAL: 300 SERIES ST. STEEL ROD
 QTY. REQUIRED: 1 PIECE

SLEEVE VALVE DRIVE COUPLING
AND SPRING SLEEVE

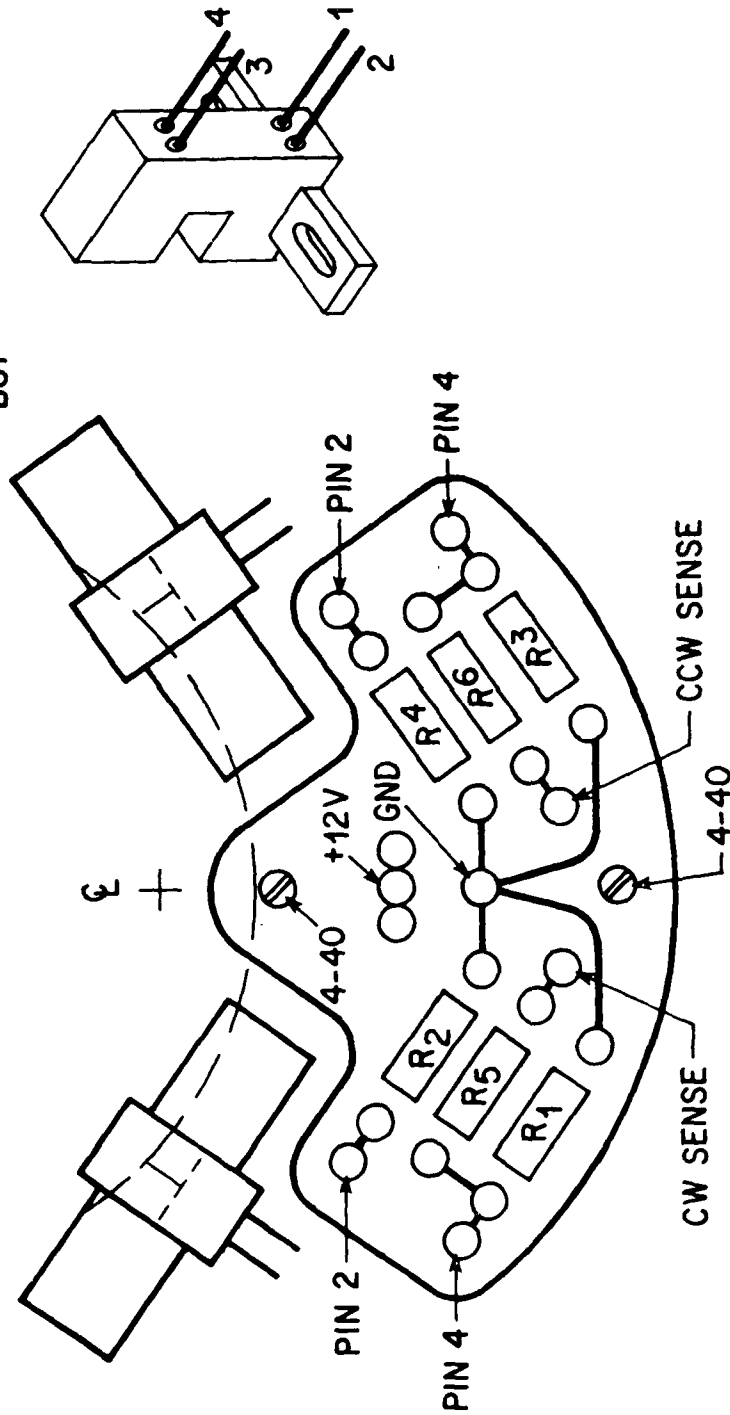
198447.121 B



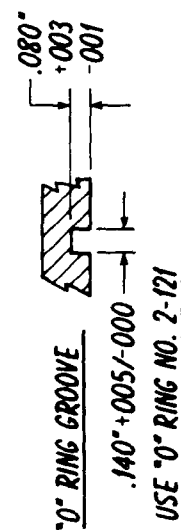
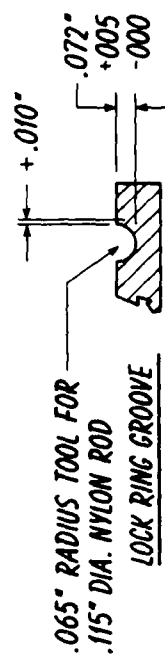
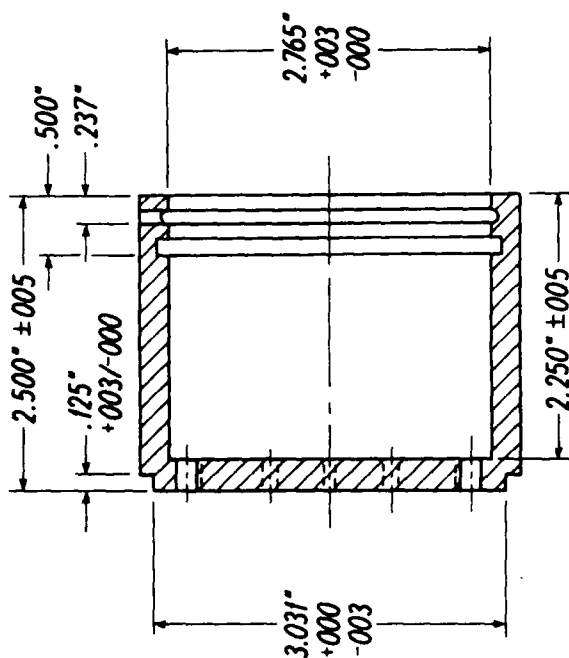
P.C. Board #3
Limit Stop Electronics
Part no. 122

+ MOTOR AXIS

OPB 837
B87



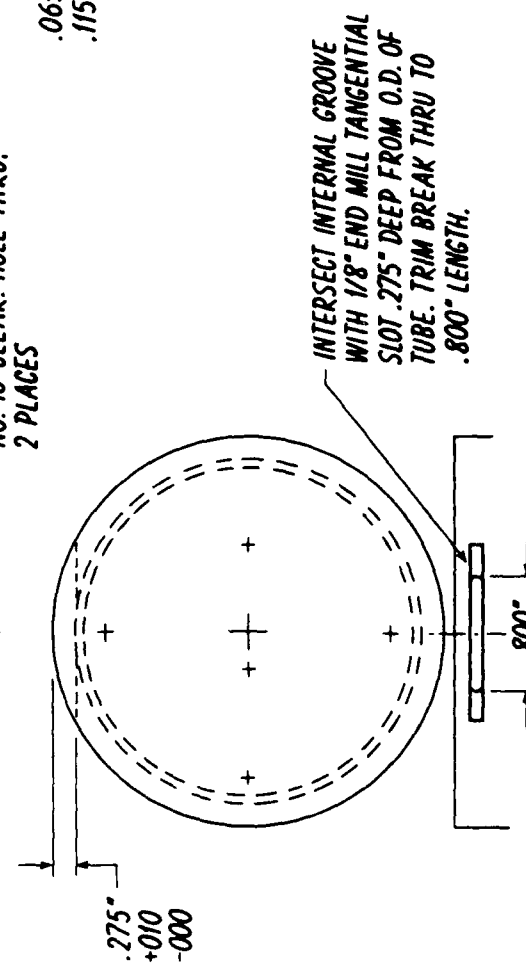
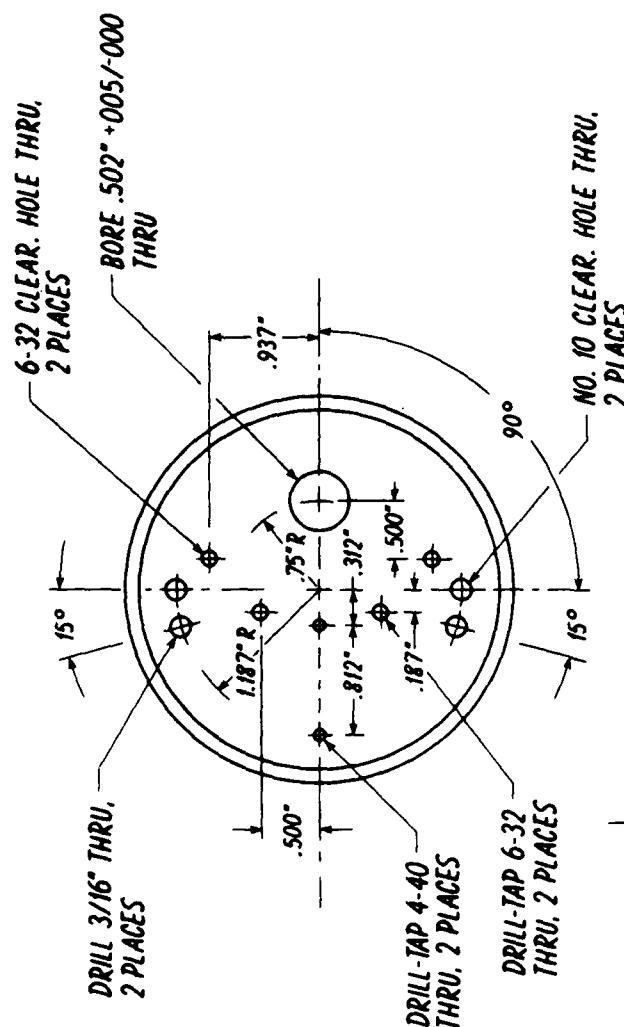
(PC-3) LIMIT STOP LAYOUT
198447.122

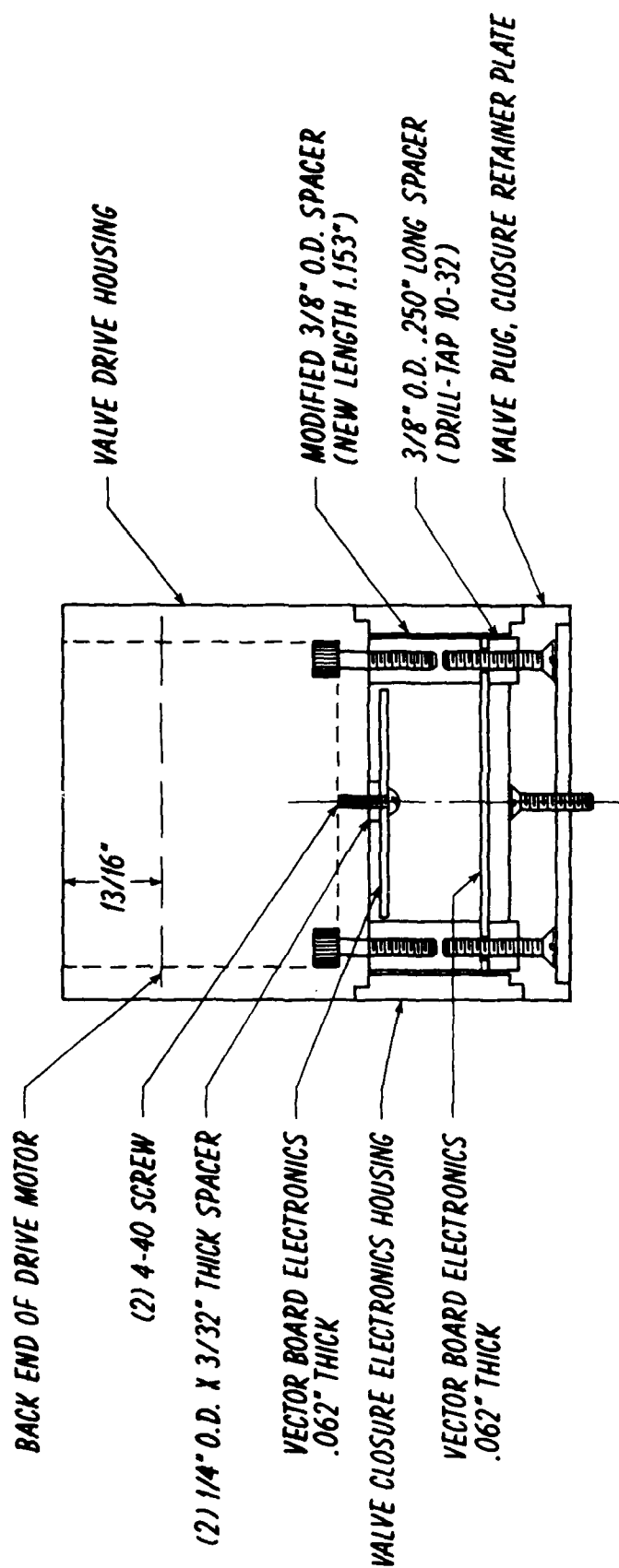


D-10 CLOSURE PLUG - MOTOR DRIVE HOUSING

198447.123

MATERIAL: PVC ROD STOCK; QTY. REQ'D: 1 PIECE

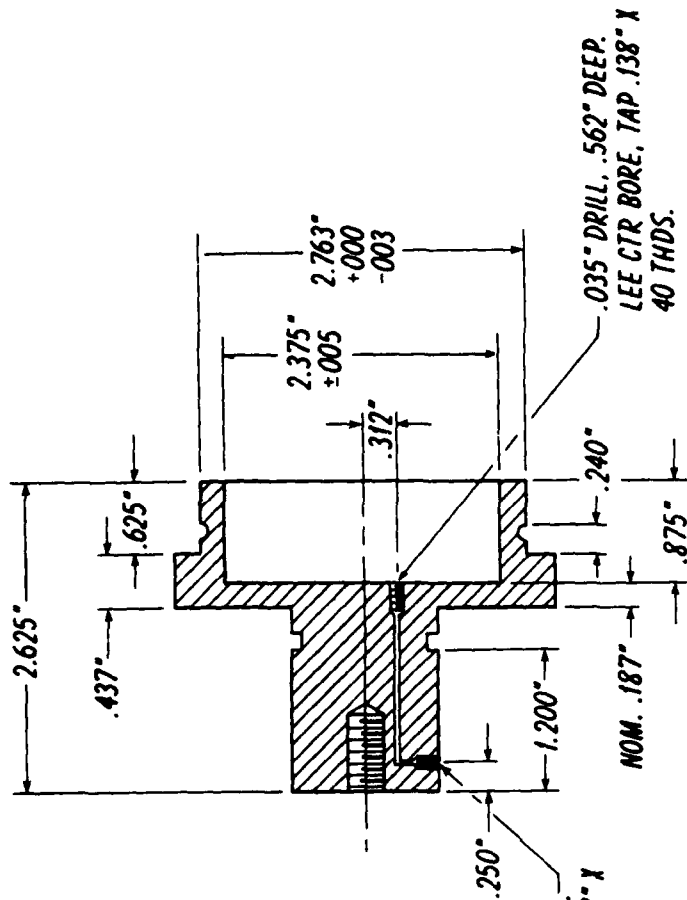




SEAL ELECTRONICS

P.C. ASSEMBLY

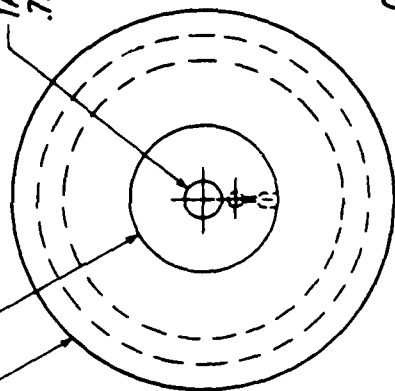
198447.125



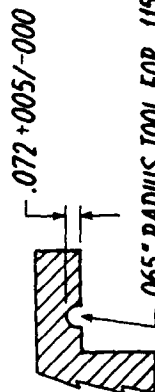
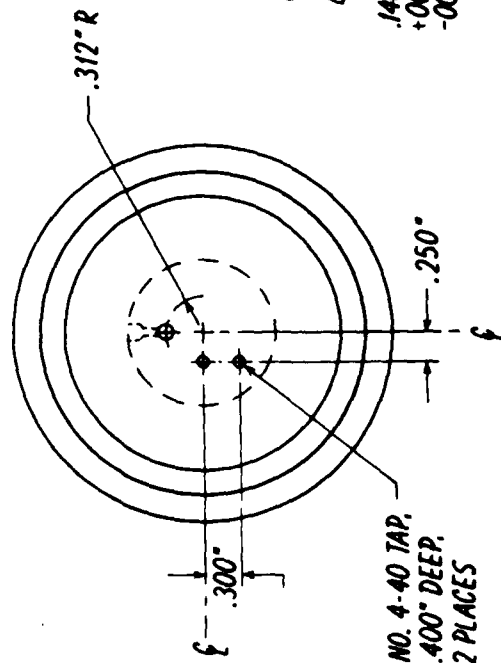
3.250" DIA. STOCK SIZE

1.250" $^{+0.000}_{-.003}$ DIA.

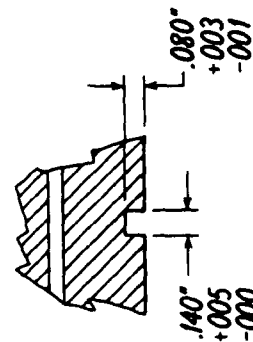
TAP 5/16-24,
.750" DEEP MAX.



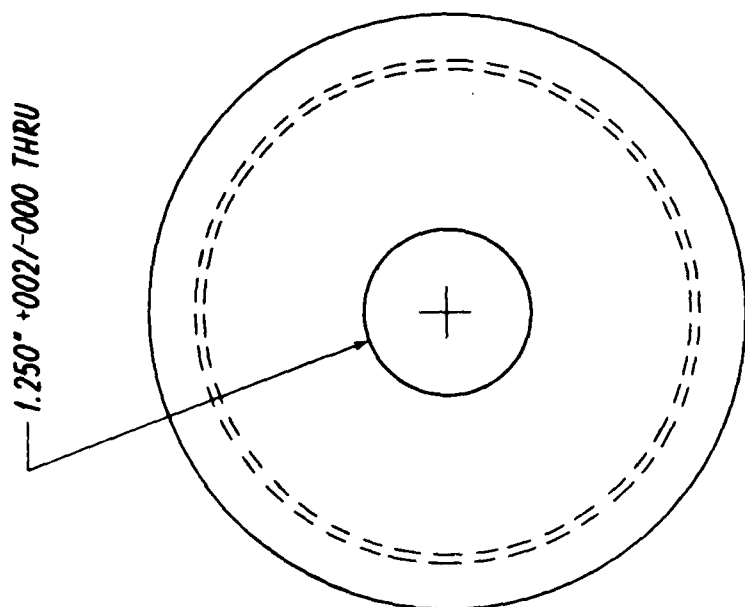
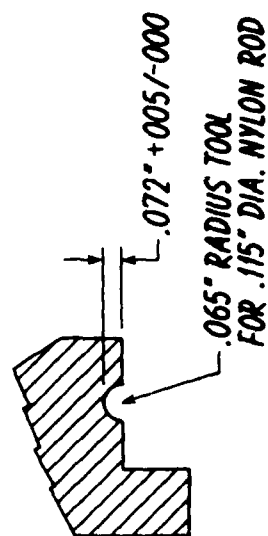
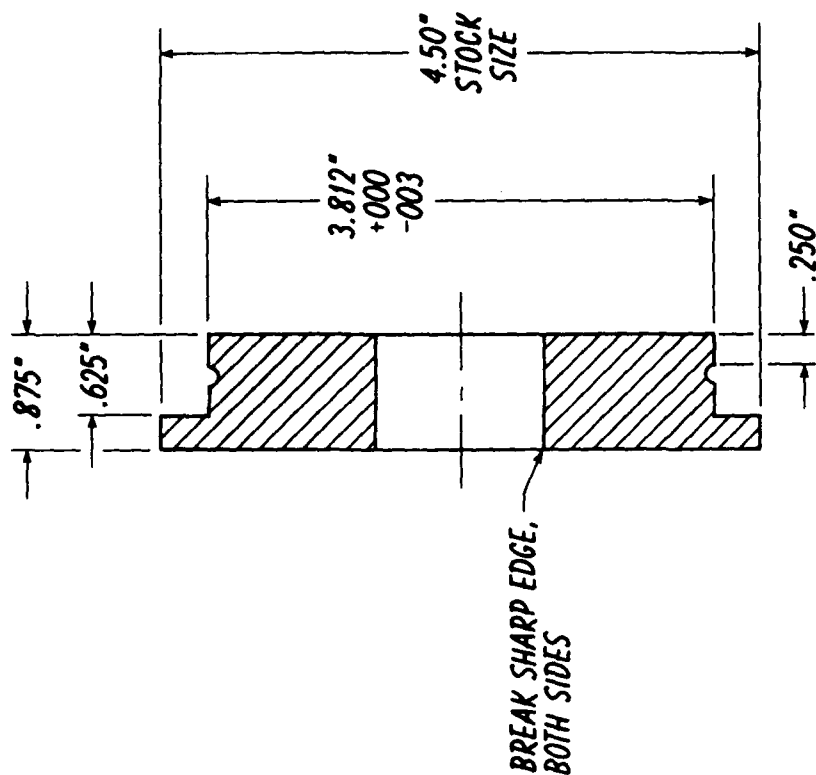
.035" DRILL, .375" DEEP.
LEE CTR. BORE, TAP .138" X
40 THDS.



USE "O" RING 2-121



DRIVE HOUSING END PLUG WITH
N2 INLET PORT 198447.126
MATERIAL: PVC, QTY. REQUIRED: 1 PIECE



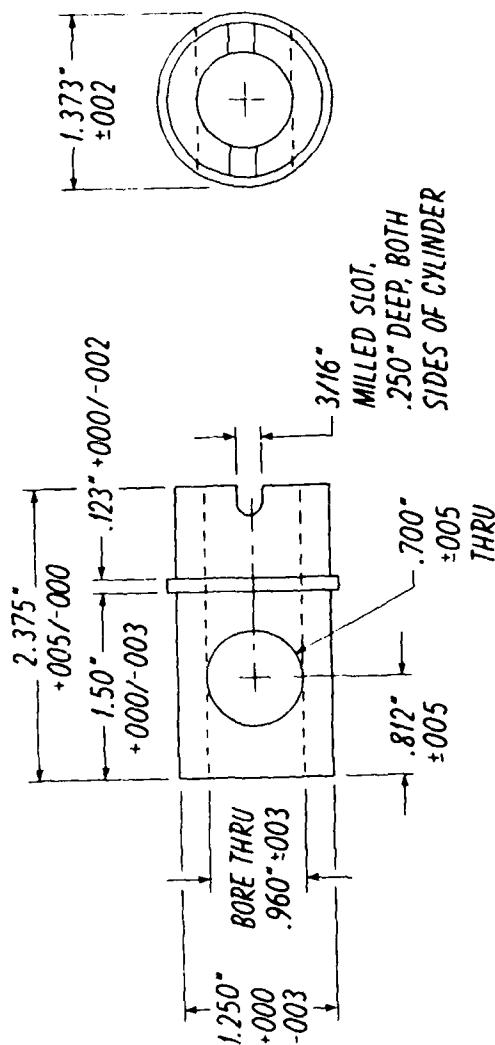
BOTTOM END CAP
198447.127

MATERIAL: PVC
QTY. REQUIRED: 1 PIECE

D-10 CLOSURE PLUG

198447.118

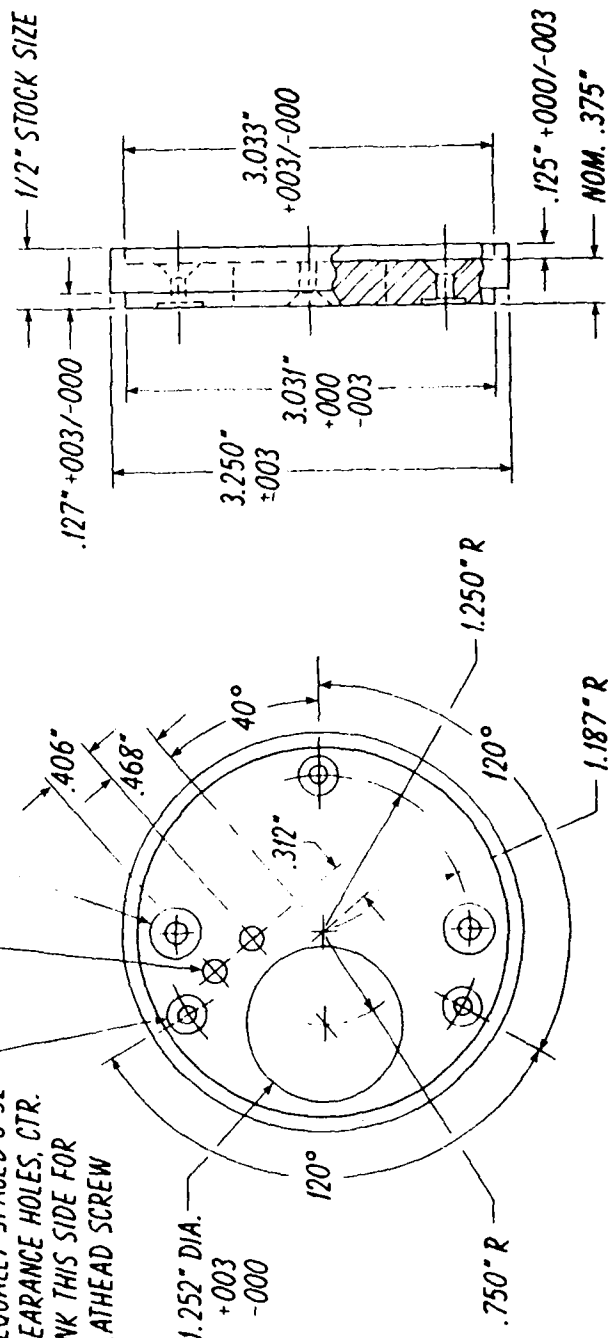
MATERIAL: DELRIN
QTY. REQUIRED: 1 PIECE



NO. 10 CLEARANCE HOLE THRU WITH
3/8" COUNTER BORE .093" DEEP. COUNTER SINK
OPP. SIDE FOR NO. 10 FLATHEAD, 2 PLACES.

3/16" DRILL
2 PLACES

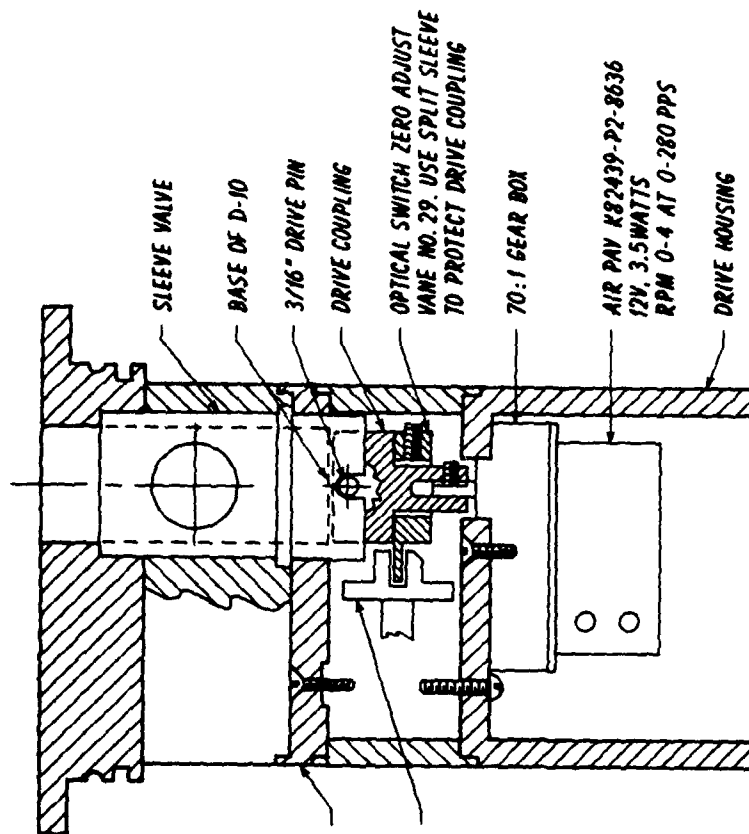
3 EQUALLY SPACED 8-32
CLEARANCE HOLES, CTR.
SINK THIS SIDE FOR
FLATHEAD SCREW



PLUG RETAINER PLATE

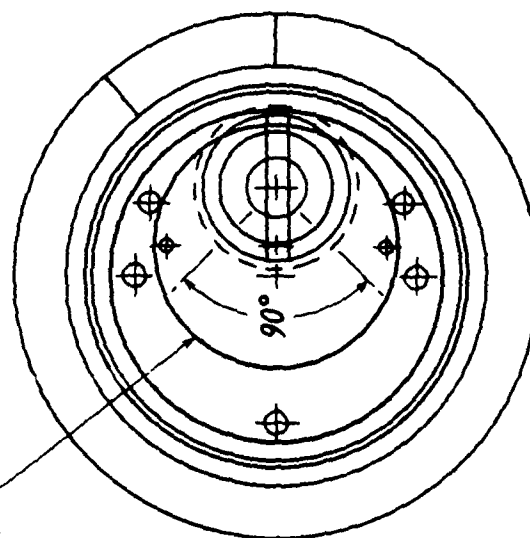
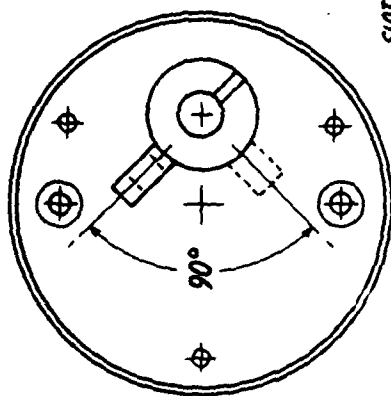
198447.128

MATERIAL: PVC
QTY. REQUIRED: 1 PIECE



CLOSURE PLUG
RETAINER
PLATE

SLOTTED OPTICAL SWITCH, TYPE 1.
USE TYPE "R" FOR EASE OF
ASSY. P/N OPB 837, 2 RECP.

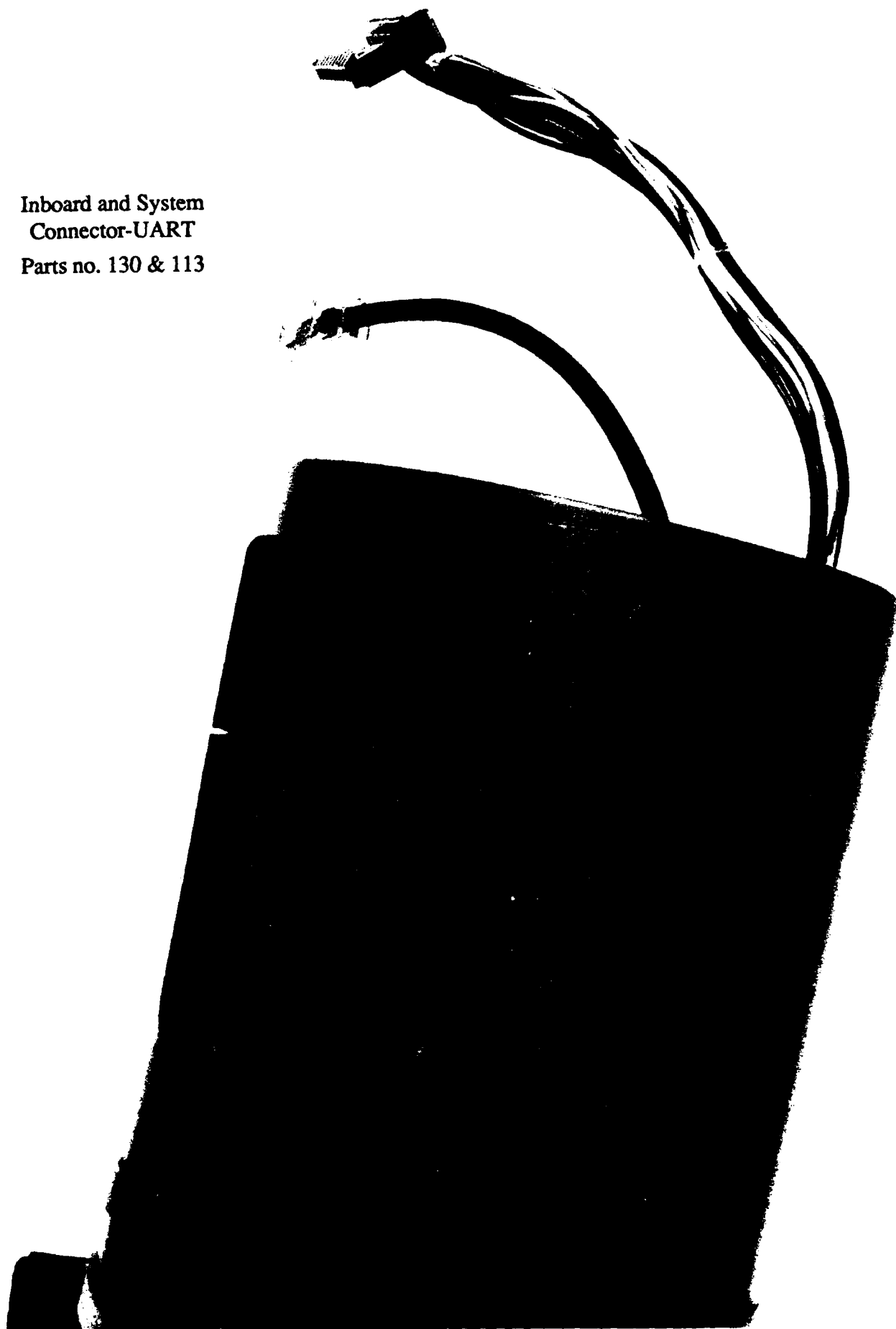


DRIVE MOTOR
OUTLINE

LAYOUT OF D-10 SLEEVE VALVE
CLOSURE MECHANISM

198447.129

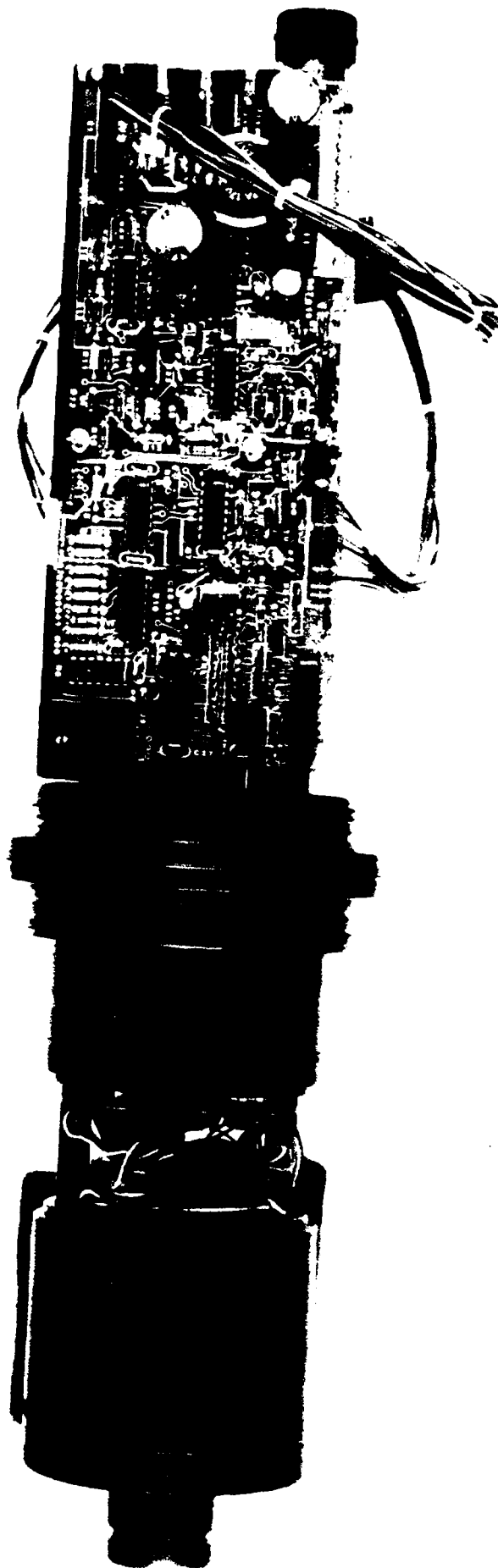
Inboard and System
Connector-UART
Parts no. 130 & 113

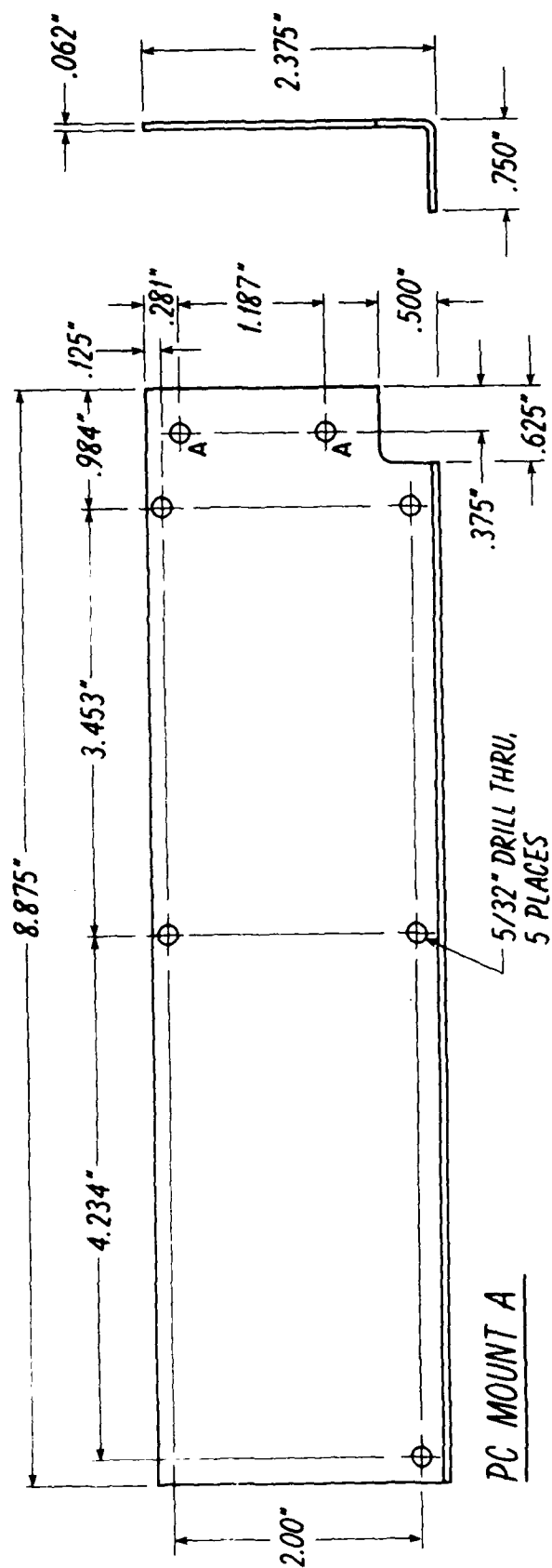


N₂ Valve
Part no. 132



Electronics Assembly showing
Main Body O-Rings
Part no. 134

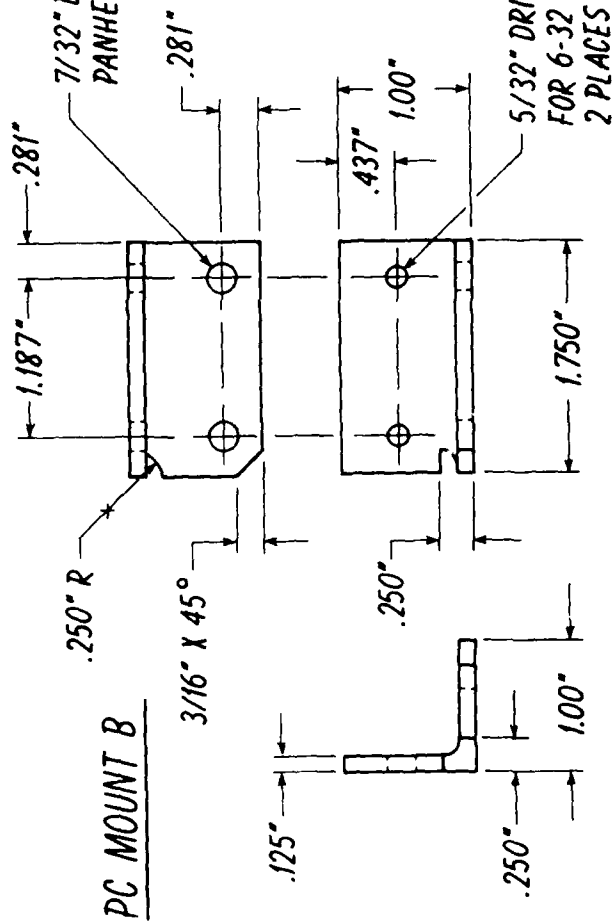




PC MOUNT A

'A' HOLES: 5/32" DRILL THRU
WITH A 1/4" C-SINK
ON OTHER SIDE FOR
6-32 FLATHEAD,
2 PLACES.

7/32" DRILL THRU FOR 10-32
PANHEAD, 2 PLACES



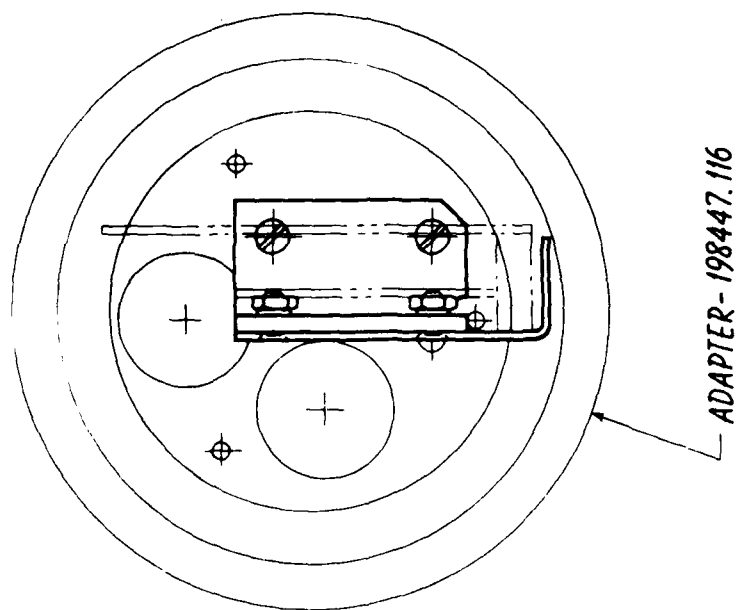
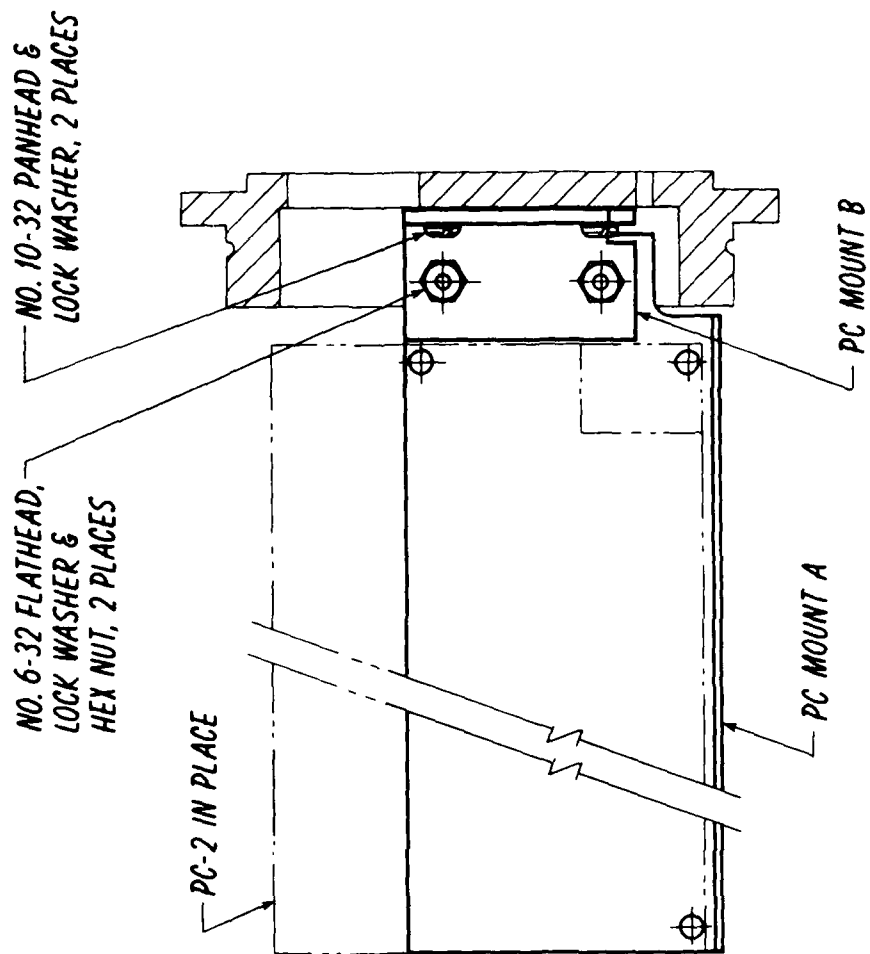
PC MOUNT B

PC-2 MOUNTING BRACKET

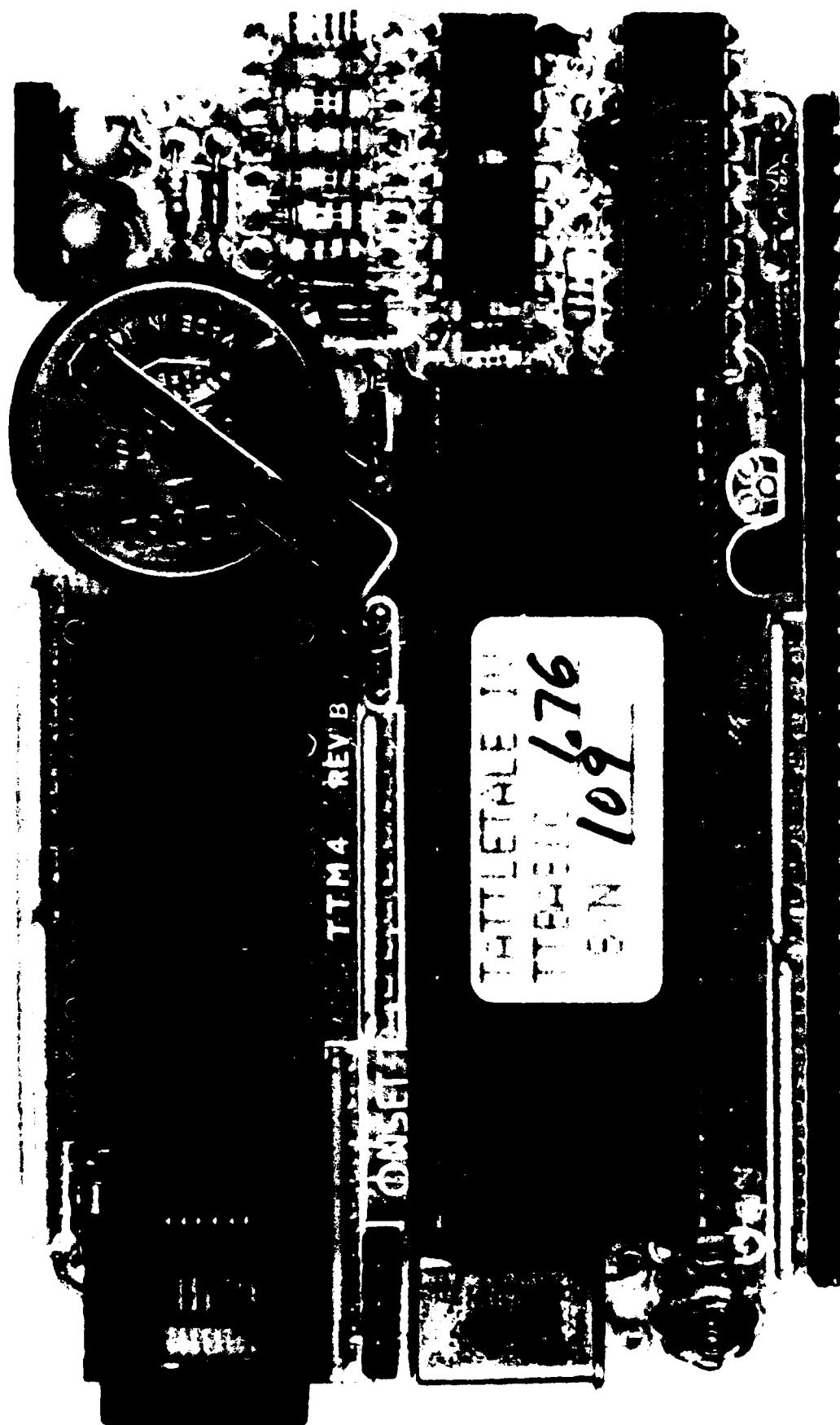
198447.136A

MATERIAL:

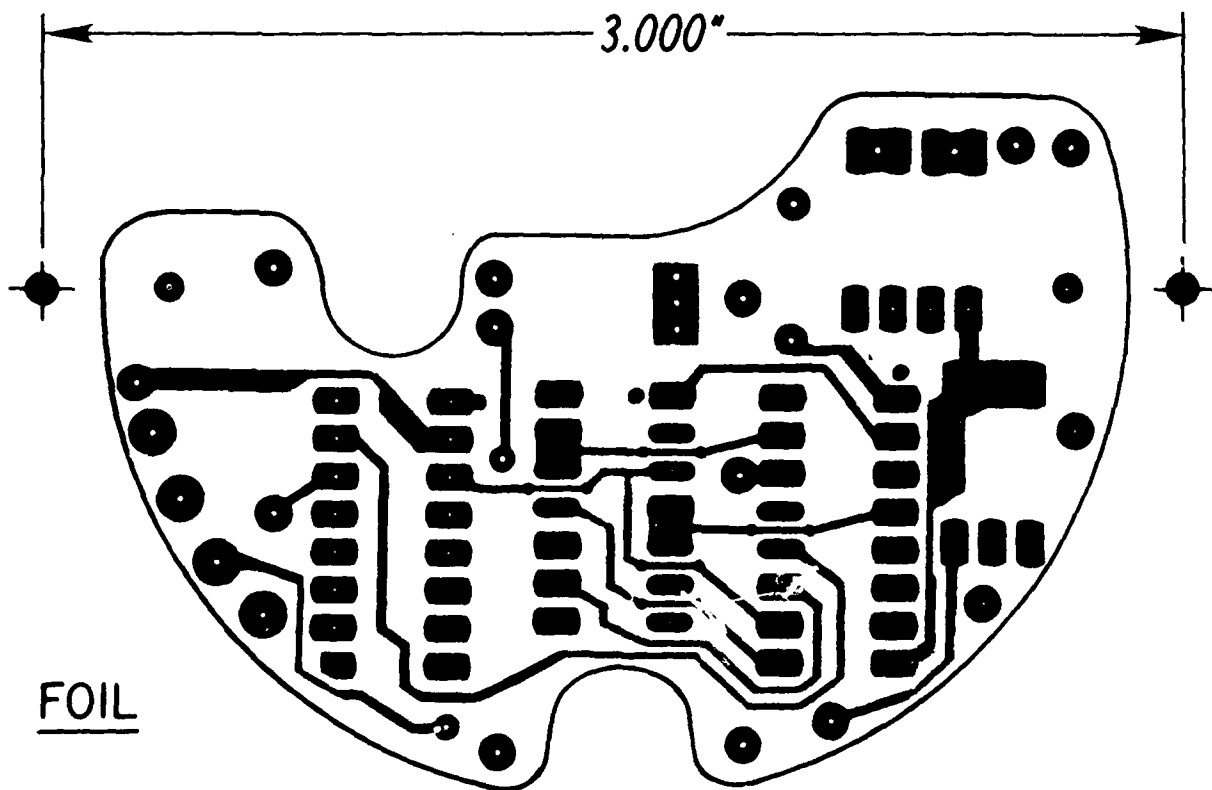
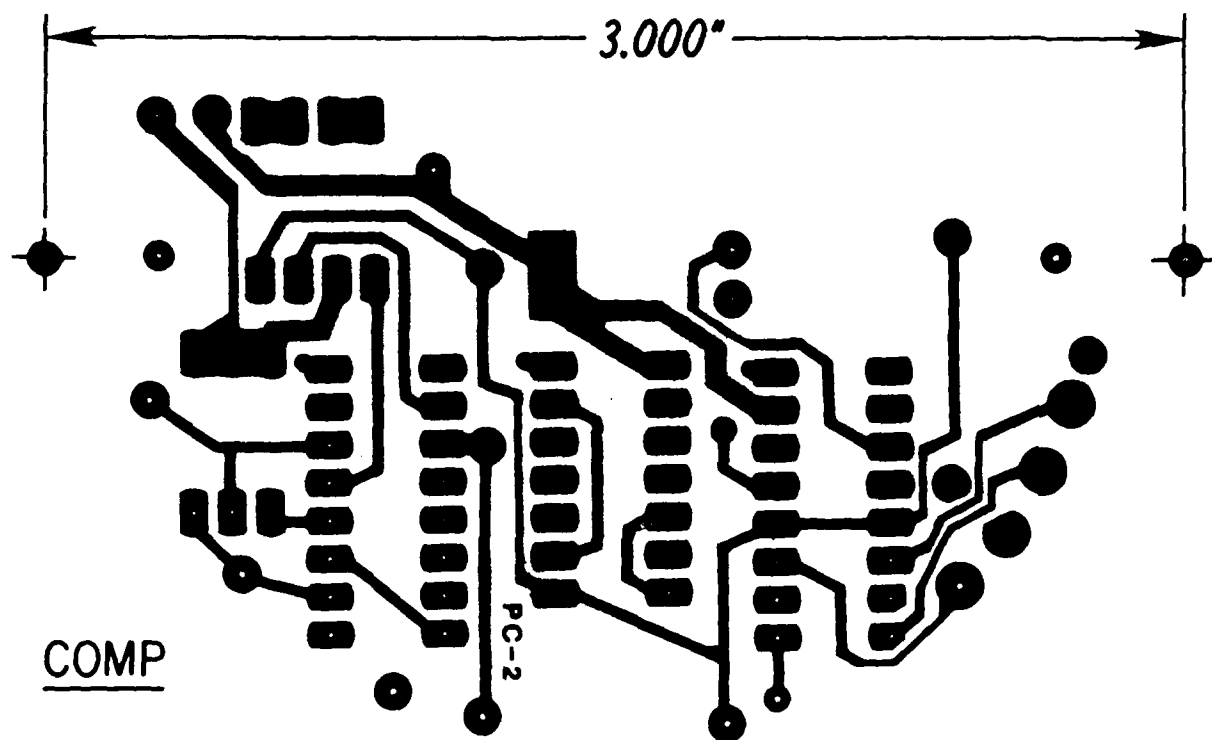
QTY. REQUIRED: 1 ASSEMBLY (198447.136B)



PC-2 MOUNTING BRACKET
ASSEMBLY & INSTALLATION
198447.136 B

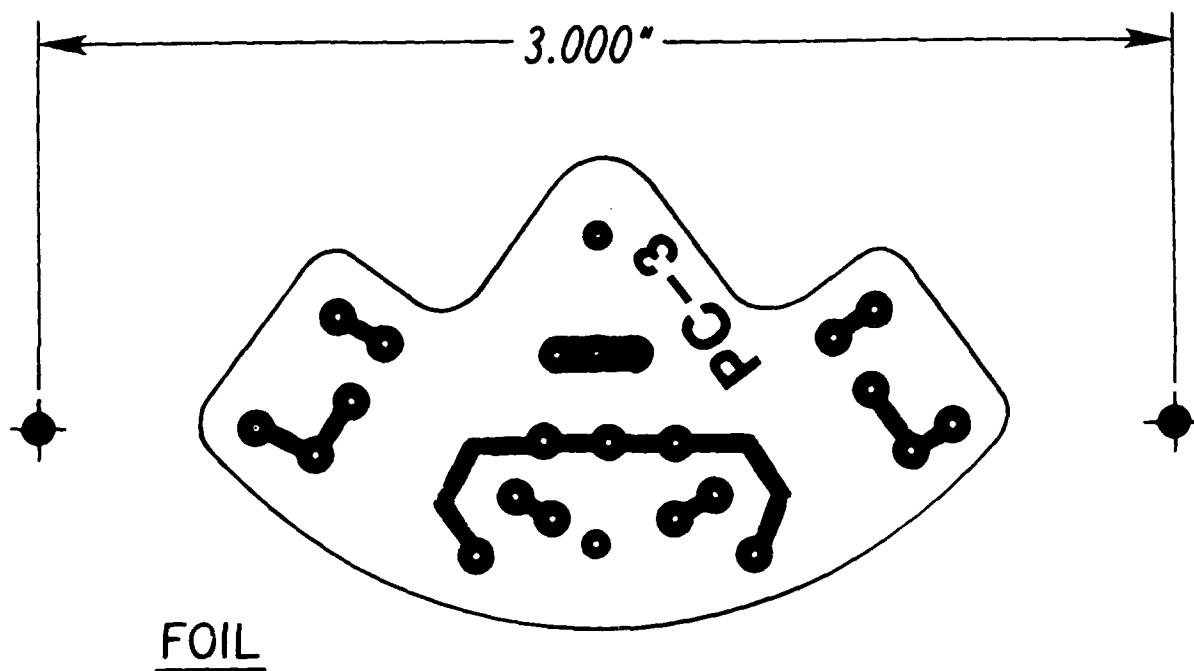


Tattletale IV Part no. 137
Microcomputer



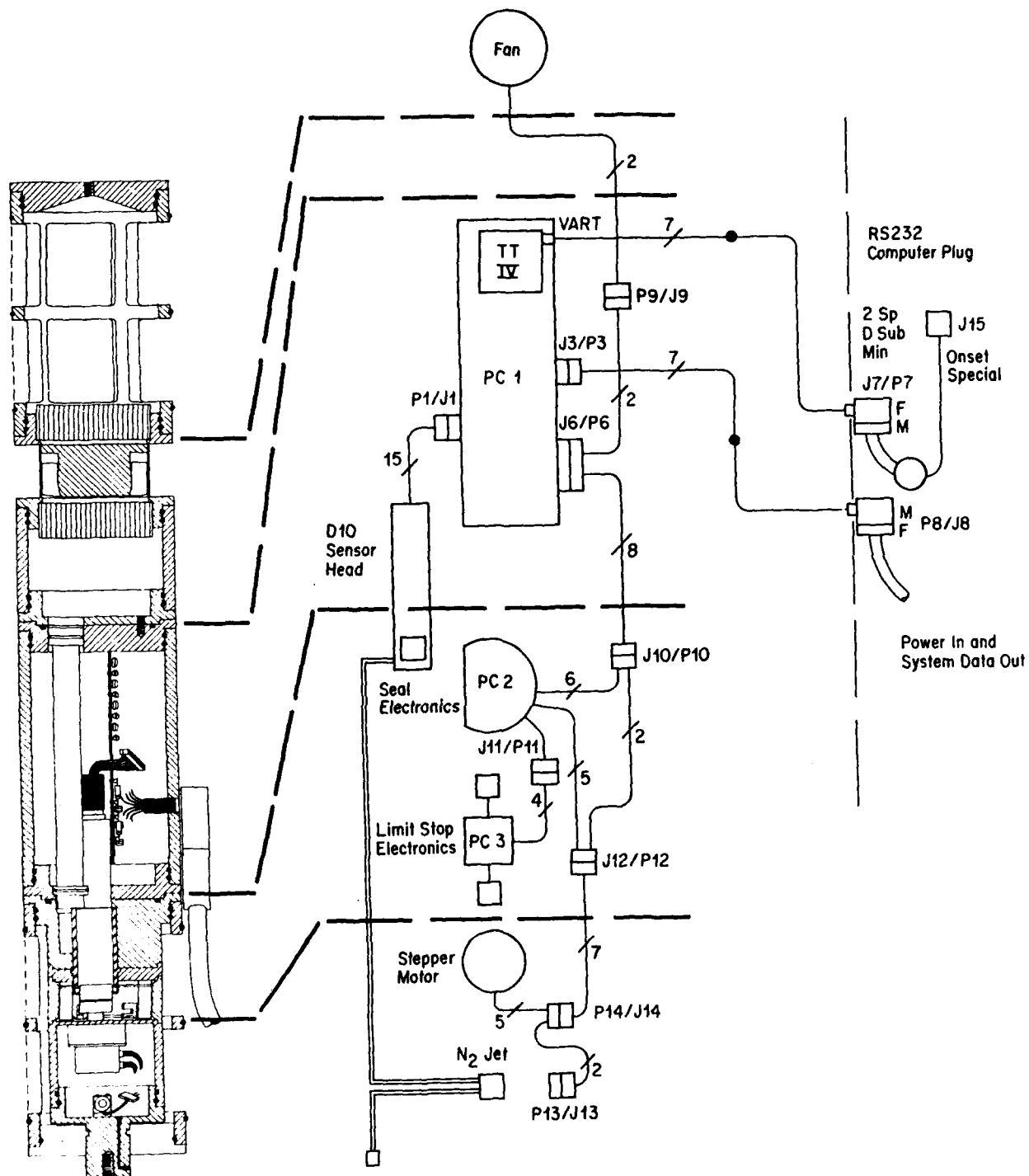
SCALE: 2X

PC-2 LAYOUT

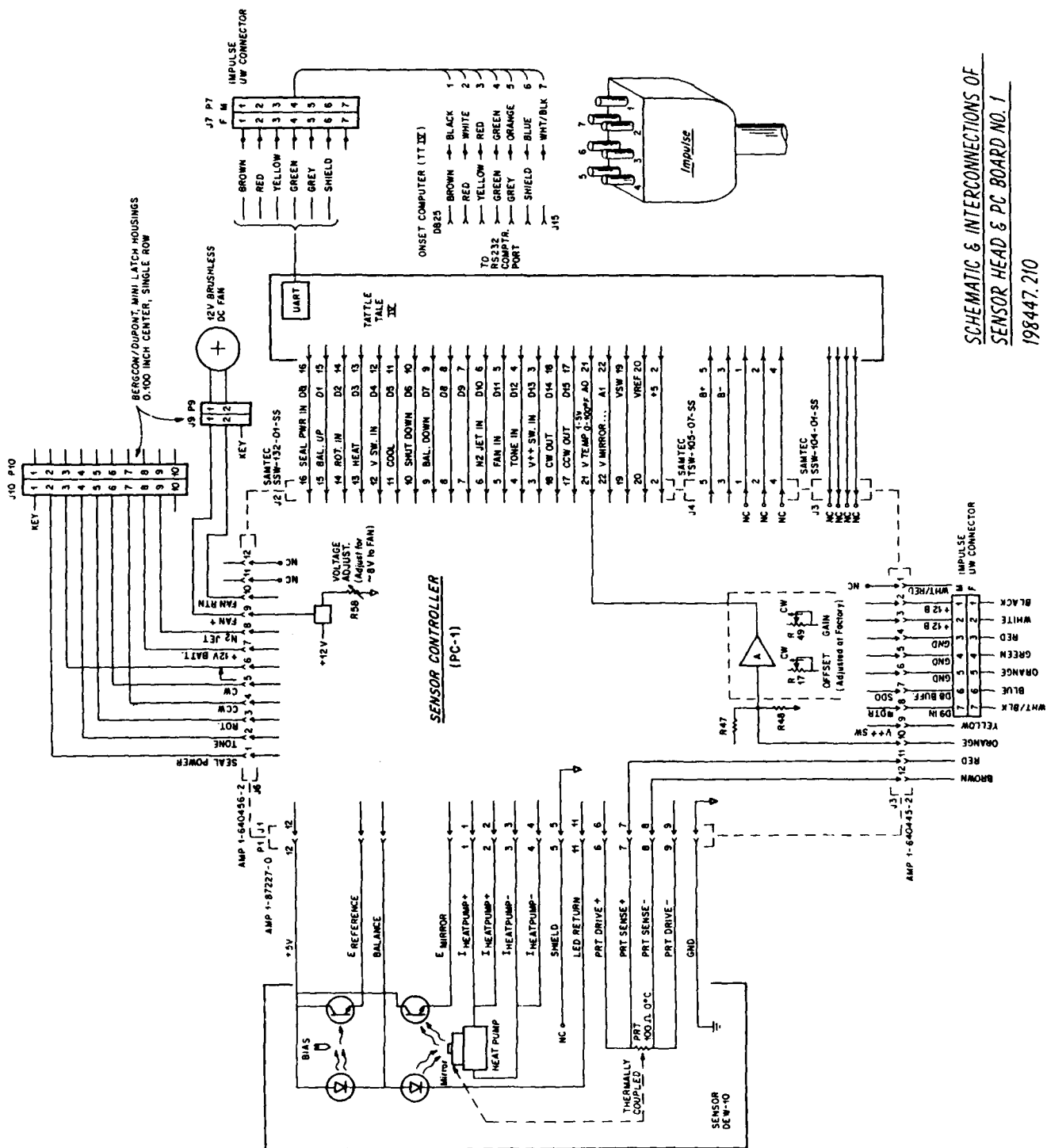


SCALE: 2X

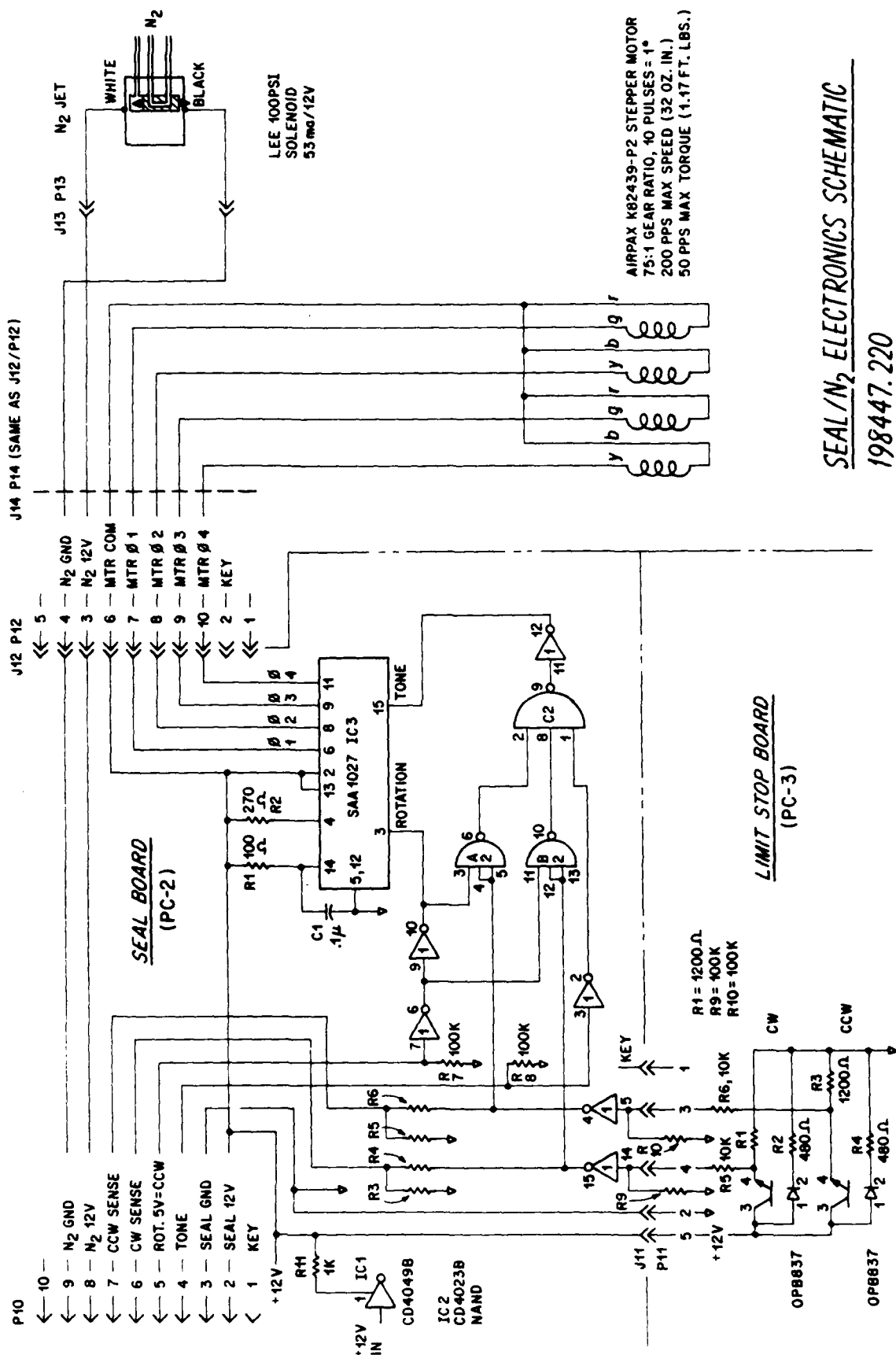
PC-3 LAYOUT



D10IQ CABLE DIAGRAM
198447.200



**SCHEMATIC & INTERCONNECTIONS OF
SENSOR HEAD & PC BOARD NO. 1
198447.210**



SEAL/N₂ ELECTRONICS SCHEMATIC

198447.220

Appendix C: Tattletale IV and Software

The software source code is listed here and can be obtained from the authors on floppy disks by covering the costs of materials and mailing. The software is intended to be self documented and uses the BASIC available on the Tattletale family of computers. The Tattletale IV is a 2.25" \times 3.725" computer with a BASIC operating system, an 11 channel - 10 bit A-to-D converter, 16 controllable input/output lines, and a battery backed up memory. Information on this is available from the manufacturer, as well as help on downloading programs from personal computers to the Tattletale. The authors used IBM-compatible personal computers with MS-DOS operating systems. The terminal program used is PC-TALK which is available at nominal cost. A Seal Test Subroutine (8300) can be used by entering a Ctrl-C from the terminal to the Tattletale to go into the BASIC operating system and then do a GOSUB 8300. This helps in doing the seal mechanism alignment. The program uses the software UART to output data and the hardware UART to provide printouts to the terminal as each part of the program is executed.

The sequence of operations was noted in Section V. The program provides output to a terminal which is useful for debugging and checking the software and hardware. The listing "Terminal Output" is a typical session and is annotated further below:

-*RUN	Standard way of starting TT so ctrl C can interrupt.
-.....Awaiting *DTR	Message output while waiting on data request.
-PREVIOUS DATA	Previous data output on serial to system.
-Seal Power On,CW	Seal being opened.
-BEGIN ASPIRATING	Fan turned on.
-.....!..	Waiting for 30 seconds prints
-DEW10 POWER ON	Power turned on to Dew-10
-ambient temp	Measures ambient temp
-pacer cycle	Starts Pacer Cycle, cools to $V_m = 1.8$ volts, then heats to $V_m = 2.5$ volts and then heats for 30 seconds more. Measures mirror volts, which indicates the level of contamination.
-Rebalance & Meas	The bridge is electronically rebalanced using an on-board D/A converter under control of the TT.
-.t..t..t..t..t	Closed loop control of the temperature by the electric cooler. Temperature being measured once each second and three temperature differences checked to be less than 0.5°F. If ok, V_m also checked to make sure it is not changing.
-dew point temp	Measured dew point temp.
-Dew-10 Power Down	Dew-10 power off.
-aspiration off	Fan off.
-Seal Power On,CCW	Seal being closed.
-N ₂ JET	N ₂ valve being opened for 5 seconds.
-CURRENT DATA	Output of data just measured.

TERMINAL OUTPUT

```

*RUN
==> DEW-10 INTELLIGENT SENSOR - ver 4.2 (03-04-88 JP/DH)
--> modified for TTBasic version 1.74
==> ... initialize system ...
==> ... initialization complete ...
... power-on RESET --- program begins automatically ...
==> ^C will enter operating system !
..... Awaiting *DTR to go low ...
....
PREVIOUS DATA
Ambient temperature   = 0.0  degrees.
Dew Point temperature = 0.0  degrees.
Mirror voltage        = 0.0  volts.
temperature, dew point, mirror voltage (tt.tdd.dv.vv<cr>)
. . .

Seal Power On, CW
Hi Torque, 1 Deg
Seal Open, Reset Counter
Power Off
BEGIN ASPIRATING CHAMBER for 30 seconds.
.....!.....!.....!
... DEW-10 POWER ON ..... 2seconds
..
ambient temperature I ==> 875
...pacer cycle...
...Vm < 1.8 volts...
...Vm > 2.5 volts...
.....!.....!.....!
..mirror voltage = K ==> 680

...Rebalance & Measure Dew Point...
...Rebalance to 3.0 <= Vm <= 3.2
...Vm Rebalanced...
...Measure Dew Point...
.....!
.t..t..t..t..t..t..t..t..t..t..v.
.....!.....!.....!
...dew point temperature J ==>742
...mirror volts B ==> 490
...Dew 10 Power Down...
... aspiration off ..

Seal Power On, CCW
Hi Speed, 90 Deg
*Seal Closed, Reset Counter
Power Off
..N2 JET ON..
.....
..N2 JET OFF..

INTERNAL TEMPERATURE = 32.3
CURRENT DATA
Ambient temperature   = 27.7  degrees.
Dew Point temperature = 18.6  degrees.
Mirror voltage        = 3.32  volts.
temperature, dew point, mirror voltage (tt.tdd.dv.vv<cr>)
27.718.63.32

```

D10IQ Software Listing

D10IQ.TT 7-18-1988 14:31 page 1

```

1 PRINT ' ==> DEW-10 INTELLIGENT SENSOR - ver 4.2 (03-04-88 JP/DH) '
2 PRINT ' --> modified for TTBasic version 1.74 '
3   SLEEP 0 : SLEEP 100

10 PRINT ' ==> ... initialize system ... '
11 PCLR 0,1,2,3,5,6,7,8,10,11,12,13
12 PSET 4
13 PRINT ' ==> ... initialization complete ... ' : SLEEP 100

20 A= 0      : REM ==> A=
21 B= 0      : REM ==> B= Vm settle and adjust variable
22 C= 0      : REM ==> C= balance adjust counter
23 D= 4      : REM ==> D= max oscillation of dew point reading(1 F=8)
24 E= 0      : REM ==> E= temporary dew point variable
25 F= 0      : REM ==> F= variable for fahrenheit conversion.
26 G= 0      : REM ==> G= seal closure counter
27 H= 0      : REM ==> H= temporary dew point variable.
28 I= 0      : REM ==> I= ambient temperature.
29 J= 0      : REM ==> J= dew point temperature.
30 K= 0      : REM ==> K= mirror voltage, with heat on
31 L= 0      : REM ==> L= ASCII conversion - amb temp
32 M= 0      : REM ==> M= ASCII conversion - dew temp
33 N= 0      : REM ==> N= ASCII conversion - mirror voltage
34 O= 0      : REM ==> O= stop/run variable on ^C
35 P= 200    : REM ==> P= .01 * P = seconds of POWER_ON warm-up.
36 Q= 0      : REM ==> Q= timing loop variable.
37 R= 0      : REM ==> R= timing loop variable.
38 S= 500    : REM ==> S= .01 * S = seconds of N2_JET ON.
39 T= 1000   : REM ==> T= .01 * T = seconds of SERVO warm-up.
40 U= 3000   : REM ==> U= .01 * U = seconds of aspiration.
41 V= 3000   : REM ==> V= .01 * V = seconds heat after Vm= 2.5 v
42 W= 100    : REM ==> W= time to process <cr>.
43 X= 0      : REM ==> X= data pointer.
44 Y= 0      : REM ==> Y= array pointer.
45 Z= 0      : REM ==> Z= variable to keep track of time.

50 @(0)= 32 : REM ==> @( 0)= mirror AMBIENT temperature
51 @(1)= 32 : REM ==> @( 1)=
52 @(2)= 46 : REM ==> @( 2)= <decimal point>
53 @(3)= 32 : REM ==> @( 3)=
54 @(4)= 32 : REM ==> @( 4)= mirror DEW-POINT temperature
55 @(5)= 32 : REM ==> @( 5)=
56 @(6)= 46 : REM ==> @( 6)= <decimal point>
57 @(7)= 32 : REM ==> @( 7)=
58 @(8)= 32 : REM ==> @( 8)= mirror CONTAMINATION voltage
59 @(9)= 46 : REM ==> @( 9)= <decimal point>
60 @(10)= 32 : REM ==> @(10)=
61 @(11)= 32 : REM ==> @(11)=
62 @(12)= 13 : REM ==> @(12)= <cr>

70 X=0 : STORE X, #1,32 : REM ==> <space>
71 X=1 : STORE X, #1,32 : REM ==> <space>
72 X=2 : STORE X, #1,46 : REM ==> <decimal point>
73 X=3 : STORE X, #1,32 : REM ==> <space>
74 X=4 : STORE X, #1,32 : REM ==> <space>

```

```

75 X=5 : STORE X, #1,32 : REM ==> <space>
76 X=6 : STORE X, #1,46 : REM ==> <decimal point>
77 X=7 : STORE X, #1,32 : REM ==> <space>
78 X=8 : STORE X, #1,32 : REM ==> <space>
79 X=9 : STORE X, #1,46 : REM ==> <decimal point>
80 X=10 : STORE X, #1,32 : REM==> <space>
81 X=11 : STORE X, #1,32 : REM==> <space>
82 X=12 : STORE X, #1,13 : REM==> <cr>

```

```

90 REM: This ensures that the program begins at power-on reset.
95 PRINT '... power-on RESET --- program begins automatically ...'
96 PRINT '==> ^C will enter operating system !'
98 SLEEP 100
99 GOTO 200

```

```

100 REM : entry point for ^C
101 SLEEP 0 : PRINT : PRINT : PRINT : PRINT : SLEEP 100

```

```

110 PRINT ' enter 0 <cr> for NORMAL RUN '
116 PRINT ' else -1 <cr> to STOP '
118 INPUT 'Please make selection --> ' O

```

```

120 IF O = 0 GOTO 200
129 IF O = -1 STOP

```

```

190 REM: In all cases (other than NORMAL RUN) return to line-100
199 GOTO 100

```

```

200 REM ==> D0 = SEAL POWER - output (0= off : 1= on)
201 REM ==> D1 = BALANCE UP - output (0 = off : 1= clock enable)
202 REM ==> D2 = SEAL ROTATION- output (0= cw,open : 1= ccw,close)
203 REM ==> D3 = HEAT* - output (0= heat : 1= off)
204 REM ==> D4 = VSW POWER - output (0= power on : 1= power off)
205 REM ==> D5 = COOL* - output (0= cool : 1= off)
206 REM ==> D6 = SHUT-DOWN - output (0= operate : 1= shutdown)
207 REM ==> D7 = BALANCE DOWN - output 0 = off : 1= clock enable)
208 REM ==> D8 = SERIAL DATA - output (serial data out)
209 REM ==> D9 = DTR INPUT - input (0= ready : 1= not ready)
210 REM ==> D10 = N2-JET - output (0= jet off : 1= jet on)
211 REM ==> D11 = ASPIRATOR 1 - output (0= fan off : 1= fan on)
212 REM ==> D12 = SEAL TONE - output (0= off frequency,counts out)
213 REM ==> D13 = DEW 10 POWER- output (0= off : 1= on)
214 REM ==> D14 = SEAL OPEN ? - input (0= no : 1= yes)
215 REM ==> D15 = SEAL CLOSED?- input (0= no : 1= yes)

```

```

300 REM ==> A0 = MIRROR TEMPERATURE - analog
301 REM ==> A1 = MIRROR VOLTAGE, CONTAMINATION - analog
302 REM ==> A2 =
303 REM ==> A3 =
304 REM ==> A4 =
305 REM ==> A5 =

```

```

306 REM ==> A6 =
307 REM ==> A7 =
308 REM ==> A8 =
309 REM ==> A9 =
310 REM ==> A10 = INTERNAL TEMPERATURE -analog

```

```

1000 REM ==> ... main program ...
1010 REM ==> check if *DTR, then send last reading, and get next!
1020 IF PIN(9) = 0 Z=0 : PRINT : GOSUB 2000
1030 SLEEP 0 : SLEEP 50
1040 Z= Z+1
1050 IF (Z% 2 = 0) PRINT '.';
1060 IF (Z% 100 = 0) PRINT ' Awaiting *DTR to go low ...'
1099 GOTO 1000

```

```

2000 REM ==> IF *DTR is 0, DATA REQUESTED
2001 REM ==> 1) send previous data and status.
2002 REM ==> 2) open seal, if open continue, if not, Vm=0.8, end cycle
2003 REM ==> 3) aspirate, turn-on power, measure amb temp
2004 REM ==> 4) pacer cycle every "B" cycles, measure mirror voltage
2005 REM ==> 5) let V temp stabilize, measure dew-point. D10 off.
2006 REM ==> 6) aspirate off, close seal, purge sensor with N2.
2007 REM ==> 7) print battery voltage and internal temperature
2008 REM ==> 8) Scale adjust: 1 to 5 volts --> 0 to 50 degrees C.
2009 REM ==> 9) Convert data to ASCII for storage.
2010 REM ==>10) Store data into data memory. wait for next data req

```

```

2100 REM ==> 1) send previous data and status.
2110 X=0
2120 USEND 1200,13,X
2140 PRINT 'PREVIOUS DATA ' : SLEEP 0 : SLEEP 100
2150 GOSUB 9100
2190 PRINT : SLEEP 100

```

```

2200 REM ==> 2) open seal, if open continue, if not, Vm=0.8, end cycle
2210 GOSUB 8100 : REM ==> open seal subroutine. G<>0 = seal stuck.
2220 IF G = 0 GOTO 2300 : REM ==> seal opened ok
2230 K = 164 : GOTO 2900 : REM ==> SET Vm= 0.8v, end cycle

```

```

2300 REM ==> 3) aspirate, turn-on power, measure ambient temperature.
2310 PSET 11 : PRINT 'BEGIN ASPIRATING CHAMBER for ',U/100,' seconds.'
2320 R = U : GOSUB 9200
2330 PSET 6,3,5,1,7,13 : PRINT '... DEW-10 POWER ON ..... ',P/100,'seconds'
2340 R = P : GOSUB 9200 : SLEEP 10
2345 C = 128 : REM ==> balance counter = 128
2350 PCLR 4 : SLEEP 10 : REM ==> turn on Vsw
2360 I= CHAN(0) : PSET 4 : REM ==> measure ambient temp, turn off Vsw
2370 PRINT 'ambient temperature I ==> ',I

```

```

2400 REM ==> 4) pacer cycle, measure mirror voltage

```

```
2410 PRINT '...pacer cycle...' : SLEEP 100
2415 GOSUB 8700 : REM ==> Pacer Subroutine
2450 PCLR 3,4 : SLEEP 10 : K= CHAN(1) : PSET 4 : REM ==> read V mirror
2460 PSET 3 : PRINT '..mirror voltage = K ==> ',K : PRINT : SLEEP 100
```

```
2500 REM ==> 5) Rebalance, measure dew point, D10 power off
2505 PRINT '...Rebalance & Measure Dew Point...' : SLEEP 100
2510 GOSUB 8500 : REM ==> Rebalance Subroutine
2515 GOSUB 8600 : REM ==> Measure Dew Point Temperature
2565 PCLR 13,1,7,5,3,6 : PRINT '...Dew 10 Power Down...' : SLEEP 100
```

```
2600 REM ==> 6) aspiration off, close seal, purge sensor with N2
2610 PCLR 11 : PRINT '... aspiration off ..' : PRINT : SLEEP 100
2620 GOSUB 8200 : REM ==> close seal G <> 0 for seal stuck
2630 IF G = 0 GOTO 2650 : REM ==> seal closed ok
2640 PRINT '..seal did not close..' : SLEEP 100
2650 PSET 10 : PRINT '..N2 JET ON..' : R= S : GOSUB 9200
2660 PCLR 10 : PRINT '..N2 JET OFF..' : REM ==> N2 jet purge
2670 PRINT : SLEEP 100
```

```
2700 REM ==> 6) Print internal temperature.
2705 PCLR 4 : SLEEP 10 : REM ==> Vsw on
2725 PRINT 'INTERNAL TEMPERATURE = ',TEMP(CHAN(10))/10,'.';
2730 PRINT TEMP(CHAN(10))*10 : SLEEP 100
2735 SLEEP 100 : PSET 4 : REM ==> Vsw off
```

```
2800 REM ==> 7) Scale adjust: 0 to 5 volts --> -25 to 100 degrees F
2810 I = ((I * 1250) / 1023) - 250 : REM --> adjust ambient temp.
2820 I = ( I-320 ) * 5 / 9 : REM --> convert F to C.
2830 J = ((J * 1250) / 1023) - 250 : REM --> adjust dew point.
2840 J = ( J-320 ) * 5 / 9 : REM --> convert F to C.
2850 K = (K * 500) / 1023 : REM ==> adjust mirror volts
```

```
2900 REM ==> 8) Convert data to ASCII for storage.
2910 L = ABS(I) : REM ==> convert ambient temp to tt.t
2920 @(3) = (L % 10) + 48 : L = L / 10
2921 @(2) = 46
2922 @(1) = (L % 10) + 48 : L = L / 10
2923 @(0) = (L % 10) + 48
```

```
2930 IF I < -99 @(2) = @(1) : @(1) = @(0)
2931 IF I < 0 @(0) = 45
```

```
2940 M = ABS(J) : REM ==> convert dew temp to dd.d
2950 @(7) = (M % 10) + 48 : M = M / 10
2951 @(6) = 46
2952 @(5) = (M % 10) + 48 : M = M / 10
2953 @(4) = (M % 10) + 48
```

```
2960 IF J < -99 @(6) = @(5) : @(5) = @(4)
2961 IF J < 0 @(4) = 45
```

```

2970 N = ABS(K) : REM ==> convert mirror volts to v.vv
2981 @(11) = (N % 10) + 48 : N = N/10
2982 @(10) = (N % 10) + 48 : N = N/10
2983 @(9) = 46
2984 @(8) = (N % 10) + 48

```

```

3000 REM ==>10) Store data into data memory, wait for next data req
3010 X = 0
3020 FOR Y=0 TO 12
3030 STORE X, #1,@(Y)
3040 NEXT Y

3050 PRINT 'CURRENT DATA ' : SLEEP 100
3060 GOSUB 9100
3070 PRINT : PRINT : SLEEP 100
3099 RETURN

```

8000 REM SUBROUTINE: UTILITIES

```

8100 SLEEP 0 : REM ==> SEAL OPEN SUBROUTINE
8105 PSET 0 : PCLR 2 : PRINT 'Seal Power On, CW': SLEEP 100
8110 G = 0 : REM ==> reset counter
8115 IF PIN(15) <> 0 GOTO 8150
8120 TONE 12288,10 : PCLR 12 : PRINT 'Hi Torque,1 Deg ': SLEEP 100
8125 IF PIN(14) <> 0 GOTO 8165 : REM ==> seal open ?
8130 IF PIN(15) <> 0 GOTO 8150 : REM ==> seal closed ?
8135 G = G+1 : PRINT 'G= ',G : SLEEP 100
8140 IF G > 1000 GOTO 8170 : REM ==> seal non operative
8145 GOTO 8120 : REM ==> take another step
8150 TONE 3072, 900 : PCLR 12 : PRINT 'Hi Speed, 90 Deg ': SLEEP 100
8155 IF PIN(14) > 0 GOTO 8165 : REM ==> seal open
8160 GOTO 8135 : REM ==> seal stuck
8165 G = 0 : SLEEP 0 : PRINT 'Seal Open, Reset Counter ': SLEEP 150
8170 PCLR 0 : PRINT 'Power Off' : SLEEP 100
8175 RETURN

```

```

8200 SLEEP 0 : REM ==> SEAL CLOSE SUBROUTINE
8205 PSET 0,2 : PRINT 'Seal Power On, CCW' :SLEEP 100
8210 G = 0 : REM ==> reset counter
8215 IF PIN(14) <> 0 GOTO 8250 : REM ==> seal open ?
8220 TONE 12288, 10 : PCLR 12 : PRINT 'Hi Torque, 1 Deg' : SLEEP 100
8225 IF PIN(15) <> 0 GOTO 8265 : REM ==> seal closed ?
8230 IF PIN(14) <> 0 GOTO 8250 : REM ==> seal open ?
8235 G = G+1 :PRINT 'G= ',G :SLEEP 100
8240 IF G > 1000 GOTO 8270 : REM ==> seal non operative
8245 GOTO 8220 :REM ==> take another step
8250 TONE 3072,900 : PCLR 12 : PRINT 'Hi Speed, 90 Deg' :SLEEP 100
8255 IF PIN(15) <> 0 GOTO 8265 : REM ==> seal closed
8260 GOTO 8235 : REM ==> seal stuck
8265 G = 0 : SLEEP 0 : PRINT 'Seal Closed, Reset Counter': SLEEP 150
8270 PCLR 0, 2 : PRINT 'Power Off' :SLEEP 100
8275 RETURN

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8300 SLEEP 0 : REM==> SEAL TEST SUBROUTINE
8305 PSET 0 : PRINT 'POWER ON ' : SLEEP 100
8310 PRINT 'ENTER 1 <CR> FOR CW ROTATION' : SLEEP 100
8315 PRINT 'ENTER 0 <CR> FOR CCW ROTATION' : SLEEP 100
8320 PRINT 'ENTER -1 <CR> FOR EXIT : SLEEP 100
8325 INPUT 'SELECT MODE A= <CR> ' A
8330 IF A = -1 GOTO 8399
8335 IF A = 1 GOTO 8350
8340 IF A = 0 GOTO 8355
8345 GOTO 8310
8350 PCLR 2 : PRINT 'CW' : SLEEP 100 : GOTO 8360
8355 PSET 2 : PRINT ' CCW ' : SLEEP 100
8360 INPUT 'ENTER A <CR> FOR A*1/10 DEG STEPS, 0 <CR> FOR RESELECT ' A
8365 IF A = 0 GOTO 8310
8370 TONE 3072, A : PCLR 12 : PRINT 'MOVED A*1/10 DEG STEPS ' : SLEEP 100
8375 IF PIN(14) <> 0 PRINT 'SEAL OPEN' : SLEEP 100
8380 IF PIN(14) = 0 PRINT 'SEAL NOT OPEN' : SLEEP 100
8385 IF PIN(15) <> 0 PRINT 'SEAL CLOSED' : SLEEP 100
8390 IF PIN(15) = 0 PRINT 'SEAL NOT CLOSED' : SLEEP 100
8395 GOTO 8360
8398 PCLR 2
8399 RETURN

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8500 REM ==> SUBROUTINE- REBALANCE ( 3.0 <= Vm <= 3.2 )
8505 PRINT '...Rebalance to 3.0 <= Vm <= 3.2 ' : SLEEP 100
8510 PCLR 6,4 : REM ==> Shutdown = operate, Vsw on
8515 IF CHAN (1) > 614 GOTO 8530 : SLEEP 100 : REM ==> Vm > 3.0
8520 PCLR 1 : SLEEP 1 : PSET 1 : REM ==> BALUP 10 milli sec pulse
8521 C = C + 1 : IF C > 255 GOTO 8560
8522 REM ==> C has range of 0 to 255, if exceeded stop operation
8525 GOTO 8515 : REM ==> Vm < 3.0 and was adjusted up
8530 IF CHAN (1) < 655 GOTO 8545 : SLEEP 100 : REM ==> Vm < 3.2
8535 PCLR 7 : SLEEP 1 : PSET 7 : REM ==> BALDN 10 millisec pulse
8536 C = C - 1 : IF C < 0 GOTO 8560
8540 GOTO 8530 : REM ==> Vm > 3.2 and was adjusted down
8545 PRINT '...Vm Rebalanced...' : SLEEP 100
8550 PSET 6,4 : REM ==> Shut down = off, Vsw off
8555 RETURN
8560 PRINT 'Cant balance mirror, set Vm = 0.4 volts and end cycle'
8565 K = 85 : GOTO 2900

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8600 REM ==> SUBROUTINE - STABILIZE AND MEASURE DEW POINT
8605 PRINT '...Measure Dew Point...' : SLEEP 100
8610 PCLR 6,4 : REM ==> Shut down = operate, Vsw on
8615 R = T : GOSUB 9200 : REM ==> Let Servo Warm Up T/100 seconds
8620 H = CHAN (0) : SLEEP 100 : PRINT '.'; : SLEEP 10
8625 J = CHAN (0) : SLEEP 100 : PRINT 't'; : SLEEP 10
8630 E = CHAN (0) : SLEEP 100 : PRINT '.'; : SLEEP 10
8635 IF ABS (H - J) > D GOTO 8620 : REM ==> Delta Td too high ?
8640 IF ABS (J - E) > D GOTO 8620 : REM ==> Delta Td too high ?
8645 IF ABS (H - E) > D GOTO 8620 : REM ==> Delta Td too high ?
8646 H = CHAN (1) : SLEEP 100 : PRINT '.'; : SLEEP 10

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8647 B = CHAN (1) : SLEEP 100 : PRINT 'v'; : SLEEP 10
8648 E = CHAN (1) : SLEEP 100 : PRINT '.'; : SLEEP 10
8649 IF ABS (H - B) > D GOTO 8620 : REM ==> Delta Vm too high?
8650 IF ABS (B - E) > D GOTO 8620 : REM ==> Delta Vm too high?
8651 IF ABS (H - E) > D GOTO 8620 : REM ==> Delta Vm too high?
8652 PRINT : R = 3000 : GOSUB 9200 : REM==> wait 30 seconds
8653 B = CHAN (1) : SLEEP 100 : J = CHAN (0)
8654 PSET 6,4 : REM==> Vsw off , shut dn = off
8655 PRINT '...dew point temperature J ==>', J : SLEEP 100
8656 PRINT '...mirror volts B ==> ', B : SLEEP 100
8660 RETURN

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8700 REM ==> SUBROUTINE- PACER CYCLE
8705 Z = 0 : PCLR 4,5,6 : REM ==> cnter=0, Vsw on, cool=on, shut dn=op
8710 IF Z > 100 PRINT '...cool 100 seconds...' : SLEEP 100 : GOTO 8725
8715 IF CHAN (1) > 369 Z = Z+1: SLEEP 100: GOTO 8710: REM ==> Vm>1.8
8720 PRINT '...Vm < 1.8 volts...' : SLEEP 100
8725 PSET 5 : REM ==> cool off
8730 Z = 0 : PCLR 3 : REM ==> counter = 0, heat on
8735 IF Z > 120 PRINT '...heat 120 seconds...': SLEEP 100: GOTO 8750
8740 IF CHAN (1) < 512 Z = Z+1: SLEEP 100 : GOTO 8735 :REM ==> Vm<2.5
8745 PRINT '...Vm > 2.5 volts...' : SLEEP 100
8750 R = V : GOSUB 9200 : REM ==> heat for V/100 seconds
8755 PSET 4,3,6 : REM Vsw off , heat off, shut dn = off
8760 RETURN

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8800 REM ==> SUBROUTINE- ADJUST SENSOR BALANCE
8805 PRINT 'To adjust sensor balance, use allen wrench to adjust '
8806 PRINT 'DEW-10 sensor head balance screw to obtain Vm = 3.1 volts'
8807 PRINT 'turn cw ==> increase Vm'
8820 PCLR 3,4 : SLEEP 10 : REM ==> heat on, Vsw on
8825 B = CHAN (1) : REM ==> read Vm
8830 PRINT 'Vm = ', B/100, '.', ABS (B % 100), ' volts' : SLEEP 100
8835 PRINT 'Enter a 1 <cr> to take new measurement' : SLEEP 100
8840 PRINT 'Enter a 0 <cr> to leave adjustment routine ' : SLEEP 100
8845 INPUT A
8850 IF A = 1 GOTO 8825
8855 IF A = 0 GOTO 8865
8860 GOTO 8835
8865 PSET 3,4 : PRINT : SLEEP 100 :REM ==> heat off, Vsw off
8870 GOSUB 8700 : REM ==> do a pacer cycle
8875 RETURN

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9100 REM ==> SUBROUTINE- FORMAT DATA TO TERMINAL
9120 PRINT 'Ambient temperature = ',I/10,'.',ABS(I%10),' degrees. '
9121 SLEEP 100
9130 PRINT 'Dew Point temperature = ',J/10,'.',ABS(J%10),' degrees. '
9131 SLEEP 100
9140 PRINT 'Mirror voltage = ',K/100,'.',ABS(K%100),' volts.'
9141 SLEEP 100
9150 PRINT 'temperature, dew point, mirror voltage (tt.tdd.dv.vv<cr>)'

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9151 SLEEP 100
9160 X=0 : OTEXT X : SLEEP 100
9199 RETURN
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9200 REM ==> SUBROUTINE WAIT AND PRINT 1 AND 10 SEC INDICATORS
9210 R = R/100 : SLEEP 0
9220 FOR Q=1 TO R
9230 IF Q%10 = 0 PRINT '!'; : SLEEP 100
9240 IF Q%10 <> 0 PRINT '.'; : SLEEP 100
9250 NEXT Q
9260 PRINT
9299 RETURN
```

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